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University of
Chester

The impact of hand-held weights on treadmill walking in previously sedentary women

Dissertation submitted in accordance with the requirements of University of Chester for the degree of Master of Science

Deborah J Savin

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ABSTRACT

Purpose

To study the physiological adaptations when hand-held weights are incorporated into a six-week programme of regular walking.

Method

Fourteen sedentary women aged 37 ± 8 yrs were randomly allocated into one of two groups; hand-held weight group (HWG) and control group (CG). Twelve women (six per group) completed the study.

Both groups completed a six-week unsupervised exercise programme comprising three 30min treadmill walks per week at 60-75% of predicted maximal oxygen uptake ($\dot{V}O_2\text{max}$). HWG carried two 0.91kg (2lb) hand-held weights using an active arm swing, CG exercised without weights. All walks were undertaken at 0% incline. Participant progress was monitored via the study website (www.sleepy8.com).

Predicted $\dot{V}O_2\text{max}$, distance walked in 10min, body mass, waist circumference and sum of four skinfold sites were measured at Baseline, Week 4 and Week 6.

Results

The 12 participants completed 100% of the programme walks.

Both groups experienced an increase in predicted $\dot{V}O_2\text{max}$; 37.0 ± 4.7 ml/kg/min to 40.0 ± 4.7 ml/kg/min (8%) for HWG, 33.4 ± 6.4 ml/kg/min to 38.9 ± 2.8 ml/kg/min (16%) for CG. These increases were neither statistically significant nor significantly different from one another.

No significant differences between or within groups were found for body mass, waist circumference or sum of four skinfold sites.

Conclusions

The addition of 0.91kg hand-held weights to a six-week regular walking programme when undertaken by previously sedentary women, does not have a significantly greater impact on aerobic fitness or body composition than unweighted walking.

Impact of hand-held weights on treadmill walking in previously sedentary women

Both forms of exercise were shown to produce meaningful improvements in aerobic fitness, but it is likely that the small sample size prevented these results from registering as statistically significant.

There is no evidence to support the introduction of hand-held weights at the beginning of a walking programme for previously sedentary women if the objective is one of accelerating the improvement in aerobic fitness or body composition. Conversely, no negative consequences of doing so have been observed here.

DECLARATION

This work is original and has not been previously submitted in support of a Degree, qualification or other course.

Signed:

Deborah Jane Savin

Date:

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Symbols and abbreviations

CHD	coronary heart disease
CVD	cardiovascular disease
BMI	body mass index (kg/m^2)
WC	waist circumference (cm)
HR	heart rate (bpm)
HRR	heart rate reserve (bpm)
HR_{max}	maximal heart rate (bpm)
BP	blood pressure (mmHg)
SBP	systolic blood pressure (mmHg)
DBP	diastolic blood pressure (mmHg)
HDL	high-density lipoproteins (mmol/L)
$\dot{\text{V}}\text{O}_2$	oxygen uptake (ml/kg/min)
$\dot{\text{V}}\text{O}_{2\text{max}}$	maximal oxygen uptake (ml/kg/min)
MET	metabolic equivalent task
M_{max}	metabolic equivalent maximal energy consumption
FCSL	freely-chosen stride length
CI	confidence interval
RR	relative risk
ACSM	American School of Sports Medicine
WHO	World Health Organization
HWs	hand-held weights
HWG	hand-held weights group
CG	control group
RPE	rating of perceived exertion
DW10	distance walked during the 10min Distance Walk Test (km)
NGS	normalised gait speed (m/s)

PREFACE

A personal story

As a recreational runner keen to complete her first marathon, running was an ever-present challenge in my life and one I relished taking on. So when spinal surgery put an end to my running endeavours, finding something to replace it that could test me in the same way was going to be difficult. I started with walking.

After a period of training my walking speed plateaued. I was keen to find a way to make the exercise more intensive without having to revert to running, something that was medically not advised. Then one day I had the idea of walking with a pair of hand-held weights. Immediately I had increased the involvement of my upper body, and was also able to walk at speeds I could not maintain for any length of time without weights in my hands.

I began to question why I was walking more “efficiently” when carrying weights; why the exercise felt less demanding despite the larger muscle mass involved and the increased speeds on the treadmill dial. Of course one person’s experiences cannot form the basis of scientific claims, but they can be the motivation behind a piece of research. So it was during many hours of weighted walking that the idea for this research took shape.

Chapter 1: INTRODUCTION

To investigate fully whether hand-held weights change in any way the benefits and outcomes of regular walking exercise, it is important first to develop a detailed understanding of the impact of walking alone on health and wellbeing.

Chapter 2 begins by presenting evidence of the well-established links between physical activity and the incidence of coronary heart disease and other chronic diseases, and more specifically the role of walking in protecting against such illnesses. This leads to a consideration of how much walking exercise is required, over what time period, and at what level of intensity in order to bring positive changes in health status and improvements in fitness.

The additional weight may alter the rhythm of walking, positively or negatively. Establishing why these alterations occur and the consequences for the walker require two things; first knowledge of the biomechanics of human walking, focussing specifically on the involvement of the upper body, and second a clear picture of the physiological differences between walking with and without hand-held weights.

In Chapter 3 the currently accepted model to explain the cause and effect of the seemingly unforced arm swing during walking is first outlined, and then consideration given to how the mechanics of walking change when arm swing becomes more vigorous. The chapter next presents a detailed review of the instantaneous physiological responses to the use of hand-held weights when walking, as reported in the literature. The closing sections of the chapter summarise the rationale for the present study and the hypotheses to be tested.

Chapter 4 provides a detailed description of the study methodology, while Chapter 5 sets out the results obtained. A full discussion of the findings, their interpretation and possible application is presented in Chapter 6.

Chapter 2: BENEFITS OF WALKING ON HEALTH AND WELLBEING

2.1. Introduction

Physical activity has a protective effect against coronary heart disease (CHD) (Berlin & Colditz, 1990). Alongside this well-established link, there is mounting evidence of the importance of adequate exercise in preventing strokes, some forms of cancer, type-2 diabetes, obesity, osteoporosis and sarcopenia (Blair & Morris, 2009).

The earliest studies into the relationship between physical activity and CHD, many conducted in the 1950s, focused primarily on physical activity in the workplace. Famously it was Morris, Heady, Raffle, Roberts and Parks (1953) who observed the significantly lower incidence of CHD in middle-aged men employed as conductors on London's double-decker buses when compared with their more sedentary colleagues sitting behind the wheel (1.9 vs 2.7 cases per 1,000 employees per year). Moreover, the authors showed that drivers were more than twice as likely to die within three months of initial diagnosis when compared to conductors.

In later studies performed on the same population, Heady, Morris, Kagan and Raffle (1961) went on to demonstrate that physical activity remained a predictor of CHD when considerations were made regarding body composition and diet, and whether or not a driver had initially been employed as a conductor. It was also observed that conductors had lower resting blood pressure (BP) and lower total plasma cholesterol levels than drivers (Kagan, 1960).

By then it had been noted (Morris & Crawford, 1958) that within modern society working life was becoming more sedentary in nature, and the damaging effects of this transformation were being recognised. So the research shifted away from analysis of the relationship between physical activity in the workplace and the occurrence of cardiovascular disease (CVD) to focus more on overall physical fitness and its relation to major chronic diseases.

2.2. Physical fitness and cardiovascular disease

Two similar cohort studies (Blair, Kohl, Paffenbarger, Clark, Cooper & Gibbons, 1989; Blair et al., 1996) observed a total of 35,565 men and 10,200 women over an average period of eight years. A baseline treadmill exercise test was used to determine maximal oxygen uptake ($\dot{V}O_{2\max}$; ml/kg/min), a measure regarded as the gold standard for assessment of cardiovascular fitness. The results of the test were used to classify subjects by fitness level, while clinical examination and a health and lifestyle questionnaire provided information on other predictors of CVD and all-cause mortality as potential confounders.

In considering the link between physical fitness and all-cause mortality, the earlier of the two studies showed that amongst men a low fitness level could be associated with a 3.44 (95% confidence interval (CI) 2.05-5.77) age-adjusted relative risk of all-cause mortality when compared to their highly active peers. For women this figure was even higher at 4.65 (95% CI 2.22-9.75), although the smaller population (23% of the study population) and fewer deaths lead to unstable results. When cause of death was CVD or cancer, the authors observed a strong inverse relationship between physical fitness and death rate for both men (trend slope -6.0 and -3.5, respectively) and women (trend slope -2.3 and -7.5, respectively), which was not apparent for other causes of death.

When $\dot{V}O_{2\max}$ was converted into a metabolic equivalent maximal energy consumption (M_{\max}) (Eq. 2.1) and plotted against age-adjusted mortality per 10,000 person-years (Figure 2.1), an interesting pattern emerged.

$$M_{\max} = \dot{V}O_{2\max}/3.5^* \quad \text{Eq. 2.1}$$

*3.5ml/kg/min = 1 MET (resting energy expenditure)

An asymptote occurred at approximately the same point irrespective of age; 9.0METs (31.5ml/kg/min) for women and 10.0METs (35ml/kg/min) for men. The authors

considered these asymptotic values to represent an optimal fitness level above which additional health benefits were not necessarily conferred.

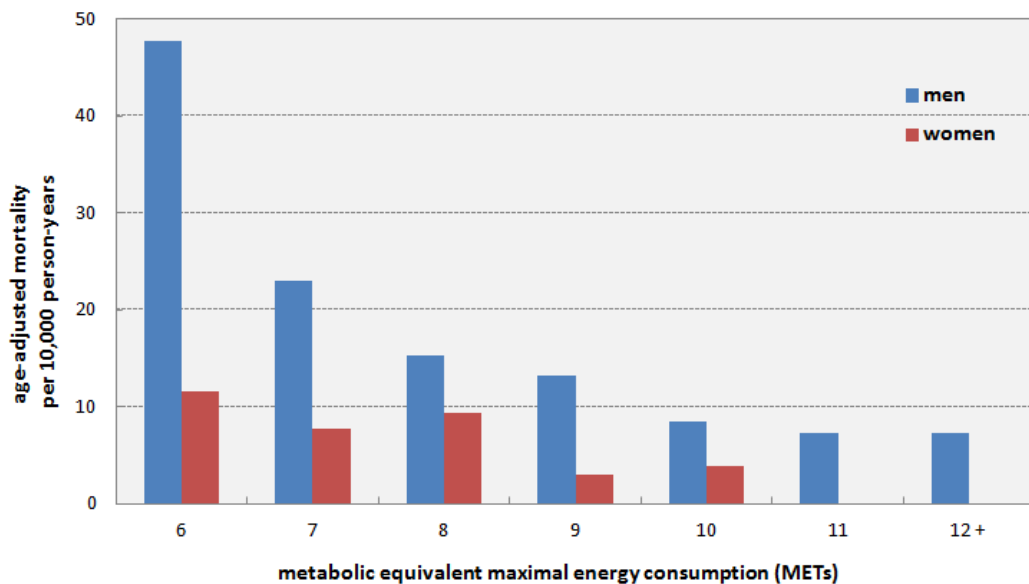


Figure 2.1: Age-adjusted all-cause mortality rates per 10,000 person-years of follow-up by fitness level in 3,120 women and 10,224 men in the Aerobics Center Longitudinal Study. (Redrawn from Blair et al., 1989)

Blair et al. (1996) observed more conservative age-adjusted relative risks of all-cause mortality in men (2.03) and women (2.23) amongst the least fit 20% of each population. After further adjustment for smoking status, resting systolic blood pressure (SBP), serum cholesterol levels, family history of CHD, BMI, fasting blood glucose level and health status at baseline, the risks reduced in both cases to 1.52 (95% CI 1.28-1.82) for men and 2.10 (95% CI 1.36-3.26). Narrowing the cause of death to CVD only, the multivariate relative risk was 1.70 (95% CI 1.28-2.25) for men and 2.42 (95% CI 0.99-5.92) for women with low fitness level. Women made up 22% of the study population.

Both studies went on to consider the death rates from CVD and all causes in cross-tabulation analysis using three levels of fitness (low, moderate, high) and two or three categories of a second mortality predictor. The results of the analysis for each of the predictors were presented graphically in the form shown in Figure 2.2.

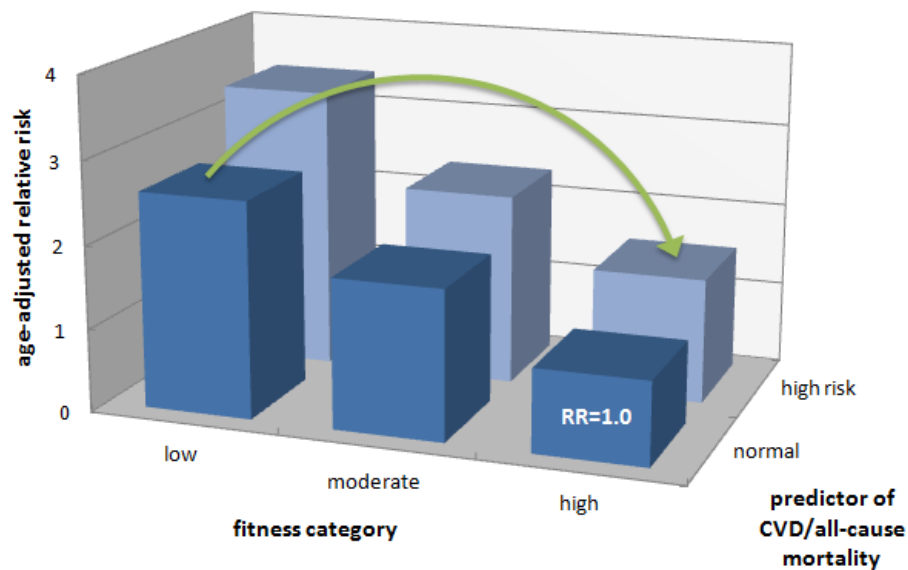


Figure 2.2: Schematic diagram showing the trends for age-adjusted relative risks of CVD or all-cause mortality by physical fitness and a second mortality predictor; smoking status, resting SBP, serum cholesterol levels, family history of CHD, BMI, fasting blood glucose level or health status at baseline. Relative risk (RR) for the front-right cell is 1.0.
(Adapted from Blair et al., 1989 and Blair et al., 1996)

An inverse relationship between increasing level of fitness and death rates from both CVD and all causes prevailed for both “normal” and “high risk” status in the second mortality predictor; one of smoking status, resting SBP, serum cholesterol levels, family history of CHD, BMI, fasting blood glucose level or health status at baseline. With only one exception, as expected the back-left (low fitness, “high risk”) cell presented with the highest relative risk in each case. The exception was family history of CHD for women (Blair et al., 1996).

However, as indicated by the green arrow in Figure 2.2, a significant finding of these studies was that in all instances, a high fitness level coupled with a “high risk” status in the second mortality predictor carried at least a similar but typically lower relative risk of death from all causes than a low fitness level plus “normal” status.

In summary, the two studies provide evidence of a strong and graded inverse relationship between physical fitness and mortality in men and women, findings that are not confounded by age or other risk factors and which highlight the importance of being active irrespective of other lifestyle choices and/or genetic make-up.

Moreover, given the data presented in Figure 2.1, the level of fitness required to provide protection against early mortality is attainable by most adults.

A limitation of these studies lies in the single administration of the exercise test at the start of the observation period, the measurement of physical fitness on which all results are based. No allowance was made for changes in physical activity in the years that followed, or for other changes in lifestyle. In their examination of sedentary behaviours and risk of obesity and type-2 diabetes in women, Hu, Li, Colditz, Willett and Manson (2003) highlighted the importance of recent physical activity as a more significant predictor of longevity than past physical activity.

2.3. Physical fitness and women's health

As is the case in the two cohort studies referenced in the preceding section, much of the initial evidence supporting the role of physical activity in the primary prevention of CVD (and other chronic diseases such as diabetes and cancer) was based on study populations comprising mostly or entirely men. In the last 15 years an increasing number of studies have focused on the role of physical activity in women's health, and specifically considered the benefits of walking exercise given its popularity amongst women (Siegel, Brackbill & Heath, 1995).

Four prospective cohort studies (Manson et al., 1999; Hu et al., 1999; Lee, Rexrode, Cook, Manson & Buring, 2001; Manson et al., 2002) assessed overall physical fitness of women-only populations through self-reported physical activity. Three of these studies used standardised classifications of the energy costs of various physical activities (e.g. Ainsworth et al., 2011) to translate the data into a weekly metabolic equivalent score for total physical activity, reported as a number of MET-hours per week. The exception was Lee et al. (2001), who presented their data in kilocalories per week (kcal/wk).

As an illustration, walking on a treadmill at 6.4km/h requires 5.0METs (Ainsworth et al., 2011). Maintaining this speed for 30min three times per week is equivalent to

$$(3 \times 30 \times 5.0) \div 60 = 7.5\text{MET-hours/wk} \quad \text{Eq. 2.2a}$$

of moderate-intensity exercise. Repeating the same pattern of exercise but at the higher speed of 7.2km/h (7.0METs) is equivalent to

$$(3 \times 30 \times 7.0) \div 60 = 10.5\text{MET-hours/wk} \quad \text{Eq. 2.2b}$$

of vigorous-intensity exercise. Vigorous activity is defined as that requiring 6.0METs or more of energy consumption (ACSM, 2009).

A summary of the key characteristics of the four studies is presented in Table 2.1.

Table 2.1: Summary of four cohort studies assessing the role of physical activity in the primary prevention of cardiovascular disease and type-2 diabetes in women.

study	population (n; age yrs)	primary endpoints	follow-up (yrs)	physical activity updates
Manson et al., 1999	72,488; 40+	non-fatal MI ¹ , death from CHD	8.0	2yrs & 6yrs
Hu et al., 1999	70,102; 40+	type-2 diabetes	8.0	2yrs & 6yrs
Lee et al., 2001	39,372; 45+	non-fatal MI, CABG ² , PTCA ³ , death from CHD	≤ 6.5	none
Manson et al., 2002	73,743; 50+	non-fatal MI, death from CHD	≤ 5.9	none

1: myocardial infarction, 2: coronary artery bypass grafting, 3: percutaneous transluminal coronary angioplasty

All four studies showed that physically active women have a reduced risk of CHD and type-2 diabetes, and identified a dose-response relationship between level of activity and these chronic diseases.

Table 2.2 shows the relative risks (RR) reported by each study after adjusting for age and accounting for confounding variables; typically age, smoking status, alcohol consumption, diet and supplementation, menopausal status, parental history of premature myocardial infarction (<60yrs) or diabetes, history of hypertension or hypercholesterolemia, and aspirin use. RR=1.0 for the lowest fitness level in each case.

Table 2.2: Relative risks (RR) and 95% confidence intervals (95% CI) of coronary heart disease or type-2 diabetes according to physical activity level.
(Results obtained from the literature sources listed)

	level 1	level 2	level 3	level 4	level 5	p value
Manson et al., 1999						
median (MET-hours/wk)	0.8	3.2	7.7	15.4	35.4	
range (MET-hours/wk)	0.0 - 2.0	2.1 - 4.6	4.7 - 10.4	10.5 - 21.7	> 21.7	
age-adjusted RR(95% CI)	1.00	0.77 (0.62-0.96)	0.65 (0.52-0.82)	0.54 (0.42-0.69)	0.46 (0.36-0.60)	< 0.001
multivariate RR (95% CI)	1.00	0.88 (0.71-1.10)	0.81 (0.64-1.02)	0.74 (0.58-0.95)	0.66 (0.51-0.86)	0.002
Hu et al., 1999 (type-2 diabetes)						
median (MET-hours/wk)	0.8	3.3	7.7	15.7	35.4	
range (MET-hours/wk)	0.0 - 2.0	2.1 - 4.6	4.7 - 10.4	10.5 - 21.7	≥ 21.8	
age-adjusted RR (95% CI)	1.00	0.71 (0.61-0.83)	0.67 (0.57-0.78)	0.52 (0.44-0.61)	0.43 (0.36-0.52)	< 0.001
multivariate RR (95% CI)	1.00	0.77 (0.66-0.90)	0.75 (0.65-0.88)	0.62 (0.52-0.73)	0.54 (0.45-0.64)	< 0.001
multivariate + BMI RR (95% CI)*	1.00	0.84 (0.72-0.97)	0.87 (0.75-1.02)	0.77 (0.65-0.91)	0.74 (0.62-0.89)	0.002
Lee et al., 2001						
range (kcal/wk)	< 200	200-599	600-1,499	≥ 1,500		
age-adjusted RR (95% CI)	1.00	0.59 (0.42-0.81)	0.42 (0.30-0.60)	0.51 (0.35-0.73)		< 0.001
multivariate RR (95% CI)	1.00	0.79 0.56-1.12)	0.55 (0.37-0.82)	0.75 (0.50-1.12)		0.03
Manson et al., 2002						
median (MET-hours/wk)	0.0	4.2	10.0	17.5	32.8	
range (MET-hours/wk)	0.0 - 2.4	2.5 - 7.2	7.3 - 13.4	13.5 - 23.3	≥ 23.4	
age-adjusted RR (95% CI)	1.00	0.83 (0.71-0.95)	0.72 (0.62-0.84)	0.63 (0.54-0.74)	0.55 (0.47-0.65)	< 0.001
multivariate RR (95% CI)	1.00	0.89 (0.75-1.04)	0.81 (0.68-0.97)	0.78 (0.66-0.93)	0.72 (0.59-0.87)	< 0.001

*authors suggested that to the extent that physical activity leads to lower BMI, adjustment for BMI in regression analysis may constitute statistical overcorrection, resulting in underestimation of the benefits of physical activity

2.3.1. The role of walking

Manson et al. (1999) and Hu et al. (1999) went on to consider the role of walking only in improving women's health by excluding those women (53%) who reported doing some vigorous exercise. The results are shown in Table 2.3.

Table 2.3: Relative risks (RR) and 95% confidence intervals (95% CI) of coronary heart disease or type-2 diabetes according to walking score.**(Results obtained from the literature sources listed)**

	level 1	level 2	level 3	level 4	level 5	p value
Manson et al., 1999						
median (MET-hours/wk)	0.0	1.7	3.0	7.5	20.0	
range (MET-hours/wk)	≤ 0.5	0.6 - 2.0	2.1 - 3.8	3.9 - 9.9	≥ 10.0	
age-adjusted RR (95% CI)	1.00	0.69 (0.50-0.93)	0.71 (0.53-0.97)	0.52 (0.38-0.70)	0.46 (0.33-0.63)	< 0.001
multivariate RR (95% CI)	1.00	0.78 (0.57-1.06)	0.88 (0.65-1.21)	0.70 (0.51-0.95)	0.65 (0.47-0.61)	0.02
Hu et al., 1999 (type-2 diabetes)						
median (MET-hours/wk)	0.0	1.7	3.0	7.5	20.0	
range (MET-hours/wk)	≤ 0.5	0.6 - 2.0	2.1 - 3.8	3.9 - 9.9	≥ 10.0	
age-adjusted RR (95% CI)	1.00	0.88 (0.73-1.07)	0.67 (0.55-0.83)	0.62 (0.50-0.77)	0.51 (0.41-0.64)	< 0.001
multivariate RR (95% CI)	1.00	0.91 (0.75-1.09)	0.73 (0.59-0.90)	0.69 (0.56-0.86)	0.58 (0.46-0.73)	< 0.001
multivariate + BMI RR (95% CI)*	1.00	0.95 (0.79-1.15)	0.80 (0.65-0.99)	0.81 (0.66-1.01)	0.74 (0.59-0.93)	0.01

*authors suggested that to the extent that physical activity leads to lower BMI, adjustment for BMI in regression analysis may constitute statistical overcorrection, resulting in underestimation of the benefits of physical activity

Walking at 6.4km/h for 30min three times per week is equivalent to 7.5MET-hrs/wk of moderate-intensity exercise (Eq. 2.2a). Following such an exercise programme could reduce a woman's risk of CHD and diabetes by 30% and 31% respectively when compared to her sedentary peers. Extending the exercise to five days per week would see these risk reductions increase to 35% and 42% respectively (Table 2.3).

Manson et al. (1999) also observed that 5.0MET-hours/wk spent walking (e.g. walking at 6.4km/h for 20min or at 4.8km/h for 30min three times per week) carried a multivariate relative risk of 0.86 (95% CI 0.74-0.99) compared with a multivariate relative risk of 0.94 (95% 0.89-0.99) for 5.0MET-hours/wk of vigorous exercise (e.g. jogging, swimming, cycling or playing tennis for 45min). This and the data presented in Tables 2.2 and 2.3 clearly indicate that both walking and vigorous exercise are associated with substantial reductions in the incidence of CHD and diagnosis of type-2 diabetes, even after confounding variables have been taken into account.

Manson et al. (2002) looked at the role of walking in a slightly different manner, considering in combination the amount of energy expended while walking and the time spent exercising vigorously. Their findings are presented in Figure 2.3. Walking at 7.2km/h for 30min three times per week is equivalent to 10.5MET-hrs/wk (Eq. 2.2b) and constitutes 90min of vigorous exercise. Following such an exercise programme could reduce a woman's age-related risk of CHD by 57% when compared to her sedentary peers.

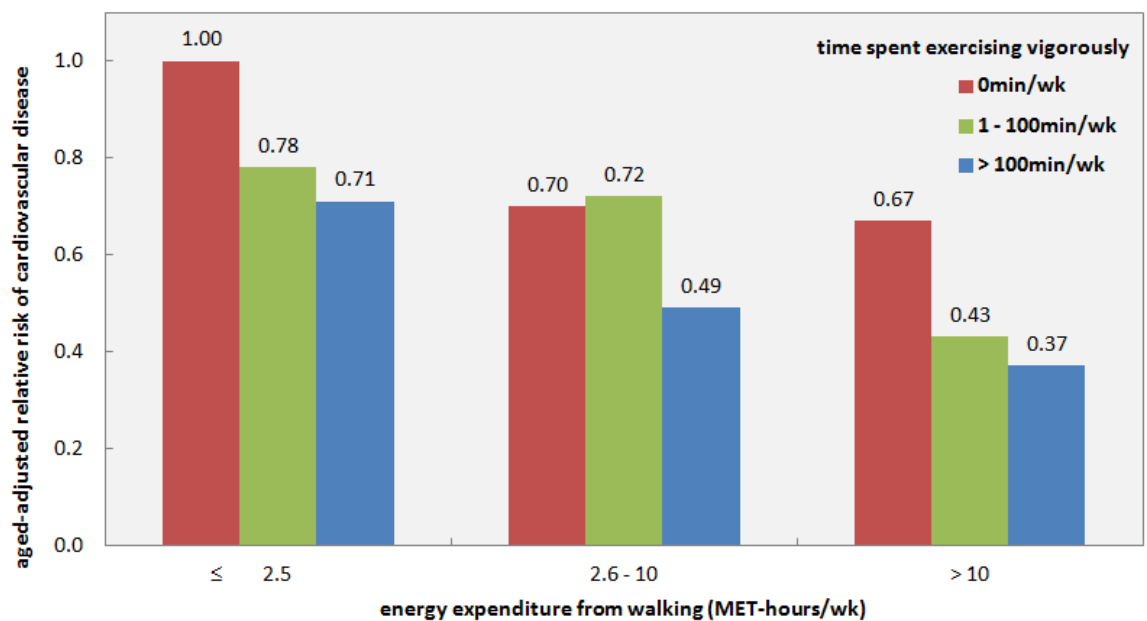


Figure 2.3: Joint association of walking and vigorous exercise with age-adjusted relative risk of cardiovascular disease ($p < 0.05$ for all comparisons with the reference group $RR = 1.0$). (Redrawn from Manson et al., 2002)

Finally, Lee et al. (2001) approached analysis of the role of walking in the prevention of CHD from two angles; time spent walking and usual walking pace. The authors considered only those women who reported doing no vigorous exercise (22,865; 58%), observing that the activity this subgroup did undertake was predominantly walking. When analysed separately, both time spent walking and usual walking pace were inversely related to risk of CHD (Table 2.4).

Table 2.4: Relative risks (RR) and 95% confidence intervals (95% CI) of coronary heart disease according to walking parameters.**(Results obtained from Lee et al., 2001)**

	level 1	level 2	level 3	level 4	p value
Parameter 1: time spent walking per week	do not walk regularly	1-59min	1-1.5hr	≥ 2hr	
age-adjusted RR (95% CI)	1.00	0.68 (0.46-0.99)	0.37 (0.22-0.62)	0.33 (0.21-0.52)	< 0.001
multivariate RR (95% CI)	1.00	0.86 (0.57-1.29)	0.49 (0.28-0.86)	0.48 (0.29-0.78)	< 0.001
Parameter 2: usual pace of walking (km/h)	do not walk regularly	< 3.2	3.2 - 4.7	≥ 4.8	
age-adjusted RR (95% CI)	1.00	0.57 (0.35-0.93)	0.50 (0.35-0.72)	0.33 (0.20-0.54)	< 0.001
multivariate RR (95% CI)	1.00	0.56 (0.32-0.97)	0.71 (0.47-1.05)	0.52 (0.30-0.90)	0.02

The authors also established that it was time spent walking ($p=0.01$ for linear trend) rather than usual pace of walking ($p=0.55$) that was significantly related to lower rates of CHD. After accounting for other confounding variables, walking for 30min three times per week appears to reduce a woman's risk of CHD by 51% when compared to her more sedentary peers (Table 2.4).

The results of the four cohort studies are encouraging; walking has a role to play in the prevention of chronic diseases in women, and moreover vigorous-intensity exercise is not essential in lowering the risks of these diseases. Given that amongst women in particular walking is a popular form of exercise, recognising that a relatively small and manageable amount carries significant health benefits is empowering. Specifically, a walking exercise programme comprising three 30min walks per week at steady pace (4.8km/h) could lead to a 14-51% reduction in the risk of CHD and at least a 25% reduction in the risk of diabetes in women. If walking pace were to increase to 6.4km/h and 7.2km/h, the reduction in risk of CHD would rise to 30-51% and 35-57%, respectively. The reduction in risk of diabetes would similarly rise to 31% and 42%, respectively.

Furthermore, such an exercise programme would be a positive step towards meeting the recommendations of the American College of Sports Medicine (ACSM) and American Heart Association (Haskell et al., 2007), which state:

“To promote and maintain health, all healthy adults aged 18 to 65yr need moderate-intensity aerobic (endurance) physical activity for a minimum of 30min on five days each week or vigorous-intensity aerobic physical activity for a minimum of 20min on three days each week.”

2.4. Walking for health and fitness

For the majority of the world's population, walking is by far the most accessible physical activity, requires little if any training to perform well, and is rarely associated with exercise-related injury (Murphy, Nevill, Murtagh & Holder, 2007). Given the relative ease with which it can be incorporated into a person's daily routine, walking is an obvious starting point when trying to introduce exercise into an otherwise sedentary lifestyle.

The benefits of regular walking are well-documented for a variety of populations. In healthy adult women (Mason et al., 1999 & 2002, Lee et al., 2001) and post-menopausal women (Hu et al., 2001), attention has focussed on the role of walking in the prevention of cardiovascular disease and other metabolic disorders. In patients with intermittent claudication for whom quality of life is a key driver, regular walking has been shown to increase tolerance to exercise, in part the result of improvements in cardiac status (Tan, Cotterrell, Sykes, Sissons, de Cossart & Edwards, 2000).

When devising a walking exercise programme, it is important to establish its main objective before deciding on frequency, duration and intensity. Is the participant's objective to increase cardiovascular fitness in order that everyday physical activities can be performed with greater ease? Maybe a family history of heart disease is motivating them to take action in an attempt to lower their risk of the same.

Several randomised control trials have set out to determine the quantity and intensity of walking necessary to improve cardiovascular fitness, lower risk of CVD, alter body composition and improve psychological wellbeing in previously sedentary but otherwise healthy adults.

Duncan, Gordon and Scott (1991) observed the effects of one of three 24-week walking programmes on 59 sedentary women aged 20-40yrs. The programmes involved walking 4.8km on five days per week at (i) aerobic pace (8km/h), (ii) brisk pace (6.4km/h), and (iii) strolling pace (4.8km/h), with a fourth group acting as control. Within each programme, distance walked and walking pace were increased incrementally.

A steep dose-response gradient was observed across the four groups for changes in maximal oxygen uptake (Figure 2.4a). The aerobic walkers, who typically exercised at 86% of their maximal heart rate (HR_{max}), experienced a 5ml/kg/min (16%) increase in $\dot{V}O_{2max}$ during the 24 weeks. The brisk walkers, who typically exercised at 67% HR_{max} , experienced a 3ml/kg/min (9%) increase. For relatively inactive adults seeking meaningful improvements in their cardiovascular fitness, these findings suggest that a brisk to aerobic walking programme could provide the physiological stimulus to achieve this within a reasonable time frame.

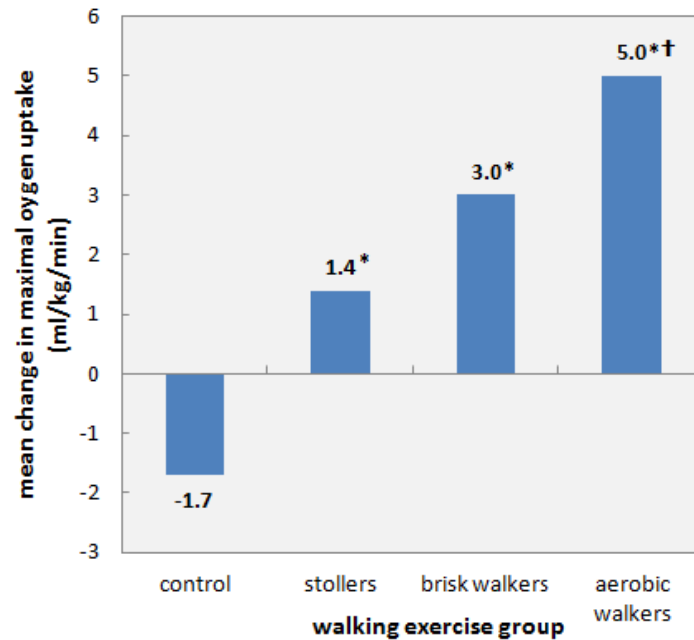


Figure 2.4a: Effect of walking intensity on changes from baseline in maximal oxygen uptake after 24 weeks of exercise training. *significant difference in change from baseline vs control; †significant difference in change from baseline vs strollers (all $p < 0.05$). (Redrawn from Duncan et al., 1991)

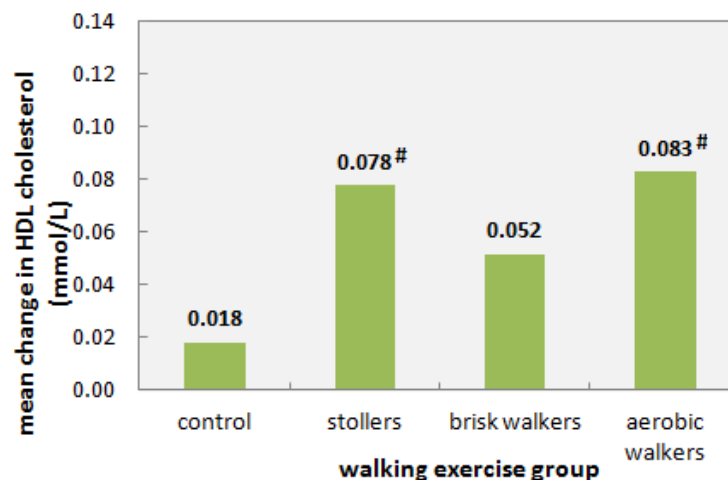


Figure 2.4b: Effect of walking intensity on changes from baseline in HDL cholesterol after 24 weeks of exercise training. #significant difference from baseline (all $p < 0.05$). (Redrawn from Duncan et al., 1991)

To assess changes in health status, the authors measured resting BP (mmHg), serum lipid levels and lipoprotein concentrations (mmol/L) before and after the 24-week exercise programmes. There was no significant change in either resting BP or total cholesterol in any of the study groups, but HDL cholesterol concentration rose notably in all three exercise groups.

Both strollers and aerobic walkers experienced a 6% (0.08mmol/L) increase in HDL cholesterol which registered as significant ($p<0.05$), while the 4% (0.05mmol/L) increase for the brisk walkers was material but not significant ($p=0.06$) (Figure 2.4b).

Clinical data has shown that for every 1% rise in HDL cholesterol there is a corresponding 3% decline in risk of CHD in dyslipidemic men (Manninen et al., 1988) and a corresponding 2% decline in risk of a coronary event in adults with stable coronary artery disease (Devendra, Whitney & Krasuski, 2010). The change of 4-6% found by Duncan et al. (1991) across all walkers suggests that, unlike fitness level, the rise in HDL cholesterol concentration is not related to exercise intensity. Moreover, regular walking exercise at 4.8km/h or faster for 24 weeks is sufficient to produce a material and health-promoting impact on HDL cholesterol concentration.

A similar study by Hardman and Hudson (1994) considered the impact of regular brisk walking on the serum lipid levels and lipoprotein concentrations of previously sedentary women. Ten women were asked to follow a 12-week self-governed exercise programme comprising 180min rising to 315min of brisk walking per week, achieved through a minimum of three 20min exercise bouts. In the subsequent 12-weeks the subjects were asked to resume their previously sedentary lifestyle. A similar population was asked to maintain their sedentary lifestyle for the 24 weeks.

The mean (s.e.m.) self-selected walking speed for the walkers was 6.3(0.11)km/h and their heart rate 130(6)bpm, corresponding to 72(3)% of predicted HR_{max} . It is therefore reasonable to expect the 12-week walking programme to improve cardiovascular fitness (ACSM, 2009).

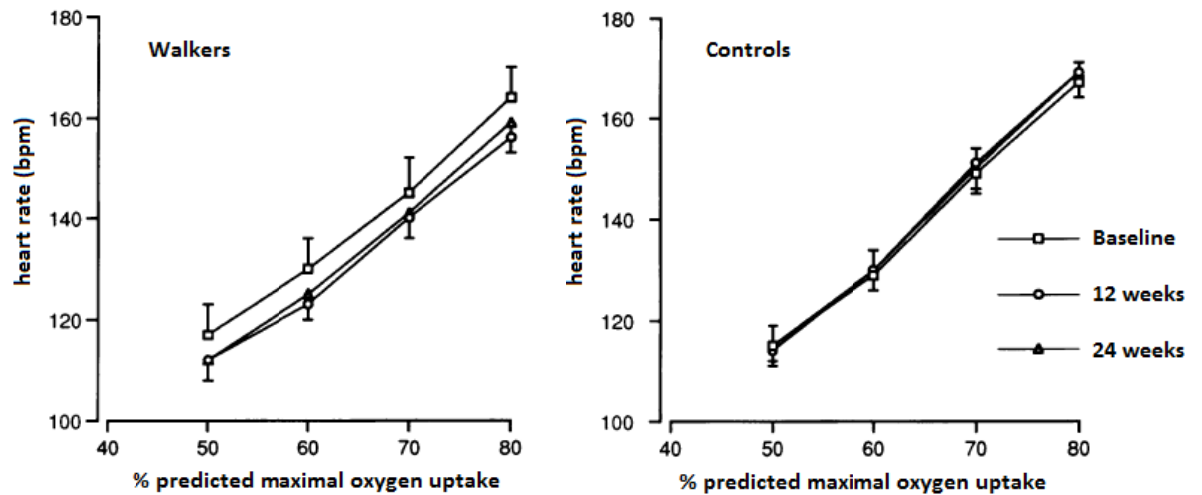


Figure: 2.5a: Mean (s.e.m.) changes in heart rate during a graded treadmill walking test for walkers and controls ($p < 0.05$).

(Adapted from Hardman & Hudson, 1994)

A graded treadmill walking test was conducted at baseline, 12 and 24 weeks. Changes over time in blood lactate and heart rate responses to exercise were significantly different between the two groups (Figures 2.5a,b). At 12 weeks, the walkers' heart rates were significantly lower at a given oxygen uptake than at baseline, as were their blood lactate concentrations ($p < 0.05$). These changes were reversed during the detraining period.

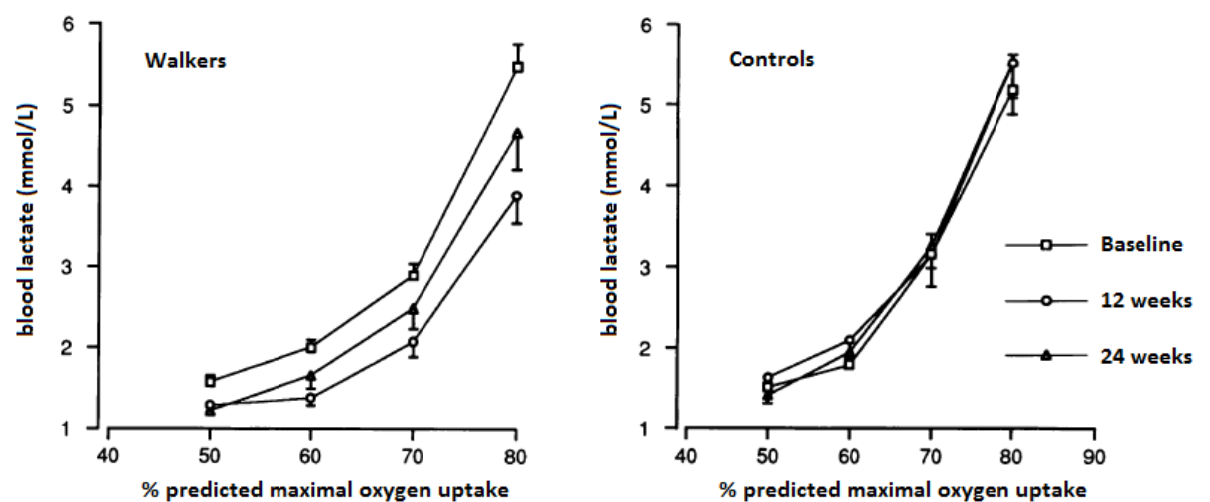


Figure: 2.5b: Mean (s.e.m.) changes in blood lactate concentrations (mmol/L) during a graded treadmill walking test for walkers and controls ($p < 0.05$).

(Adapted from Hardman & Hudson, 1994)

Alongside these improvements in endurance fitness, the walkers experienced an increase in HDL cholesterol concentrations similar to those observed by Duncan et al. (1991). By 12 weeks the walkers' HDL cholesterol had increased by 5% (0.06mmol/L), a significant rise from the baseline measurement ($p<0.05$). After returning to a sedentary lifestyle for a further 12 weeks, this training effect had completely reversed (Figure 2.6). There were no changes in HDL cholesterol for the controls.

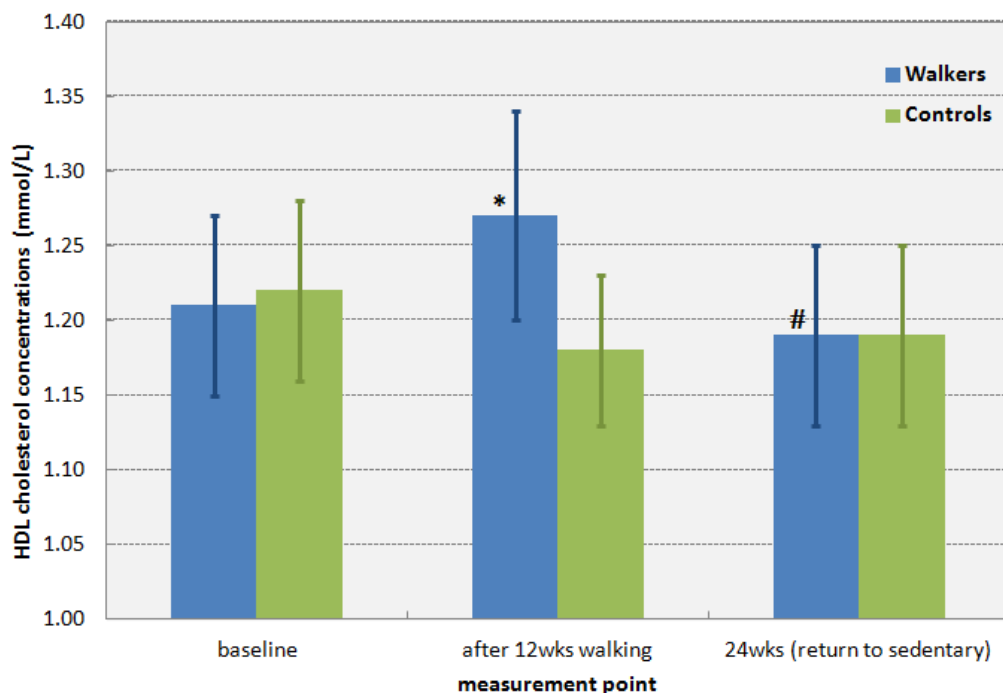


Figure 2.6: Mean (s.e.m.) HDL cholesterol concentrations in walkers and controls at baseline, 12 weeks and 24 weeks. *significant difference from baseline; #significant difference from 12 weeks (both $p<0.05$).

(Results taken from Hardman & Hudson, 1994)

The mean (s.e.m.) amount of brisk walking undertaken by the walkers was 187(6)min during the first two weeks, rising to 292(7)min during the final six weeks, information obtained from training diaries submitted by subjects. This data reflects adherence to the prescribed walking programme of 104% at the outset falling no lower than 93% throughout, a promising outcome if the objective is to identify an exercise programme that delivers meaningful cardiovascular health and fitness improvements to which previously sedentary women feel able to commit.

In an attempt to ensure adherence to a more physically active lifestyle, Murphy, Nevill, Neville, Biddle and Hardman (2002) investigated whether more frequent but shorter bouts of brisk walking (3×10min, 5days/wk) promoted health benefits and improvements in cardiovascular fitness commensurate with those derived from fewer but longer bouts of the same activity (1×30min, 5days/wk).

The study used a cross-over design comprising two six-week self-governed exercise programmes as shown in Table 2.5. Previously sedentary subjects were instructed to walk briskly at a pace equating to 70-80% of their predicted HR_{max} .

Table 2.5: Structure of and adherence to the exercise programmes in the cross-over design study undertaken by Murphy et al., 2002.

		Week 1 – 6	Week 7 & 8	Week 9 – 14
Group 1	N	short bouts (3 × 30min)	washout	long bouts (1 × 30min)
adherence (excl. < 60% compliance*)	13	92.6%	n/a	90.9%
drop outs	2	1	1	0
Group 2	N	long bouts (1 × 30min)	washout	short bouts (3 × 30min)
adherence (excl. < 60% compliance*)	8	85.1%	n/a	86.2%
drop outs	7	2	1	4

***adequate compliance was defined as completion of 60% of prescribed walks and one person in each group failed to meet this requirement despite reaching the end of Week 14**

When considered in combination, the dropout rates and levels of adherence present a strong argument for exercise programmes to begin as a series of short bouts which over time combine to deliver the same total amount and intensity of physical activity but in fewer longer bouts.

Predicted $\dot{V}O_2max$ increased significantly during both six-week programmes but the increase was greater after the short-bout programme (14.2% or 3.95 ± 3.21 ml/kg/min, $p < 0.05$) than the long-bout programme (3.8% or 1.1 ± 3.21 ml/kg/min, $p < 0.05$). However, examination of these results by group shows that this pattern was only evident for Group 1. For Group 2 the increase in $\dot{V}O_2max$ was comparable after both exercise programmes (Figure 2.7).

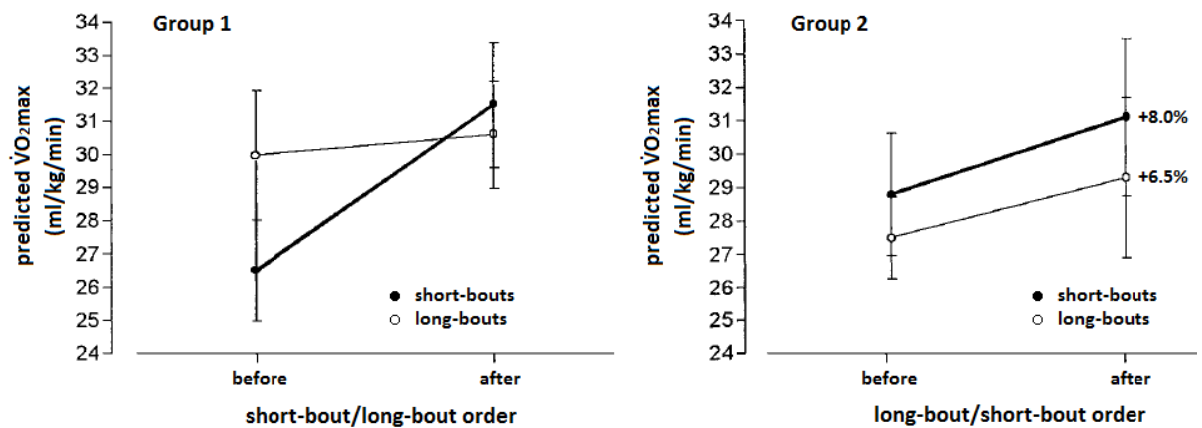


Figure 2.7: Predicted $\dot{V}O_{2\max}$ before and after short and long bouts of brisk walking for subjects completing programmes in short-bout/long-bout order (N=13) and long-bout/short-bout order (N=8). (Adapted from Murphy et al., 2002)

Given the well-established fact that increases in $\dot{V}O_{2\max}$ are greatest early on in a training programme, the greater adherence rate of Group 1 may explain the more dramatic improvement in $\dot{V}O_{2\max}$ observed during their first six weeks of walking when compared with the same period for Group 2. It is also clear from Figure 2.7 that the washout period was insufficient in length to reverse the improvement in cardiovascular fitness, further impacting the results.

The mean $\dot{V}O_{2\max}$ of the 21 subjects who completed two exercise bouts increased from 26.9 ± 4.8 ml/kg/min to 30.8 ± 6.0 ml/kg/min, or by 14.5% over the 14 weeks, with the majority of this net increase (14.1%) occurring during the first exercise bout. Although the authors did not comment on whether this increase was statistically significant, it certainly falls within the minimum range of $\dot{V}O_{2\max}$ improvements (10-15%) expected with adherence to ACSM exercise guidelines (ACSM, 1998).

Both patterns of brisk walking produced a significant increase ($p < 0.05$) in HDL cholesterol concentration during a six-week period. The increase in mean HDL cholesterol concentration during short bouts of exercise was 5% (0.07 mmol/L) whereas during long bouts it was 9% (0.12 mmol/L). These results were not significantly different.

Murphy et al. (2002) also assessed various indices of psychological health, one being perceived barriers to exercise. Fifteen barriers to brisk walking exercise were grouped into four sub-categories (effort, time, obstacles and health) and rated by subjects on a scale from 1 ("strongly disagree") to 5 ("strongly agree") before and after each six-week programme. Mean scores for all four sub-categories decreased during both exercise patterns, showing a weakening in the impact of each barrier-type. Two of these changes were significant ($p < 0.05$); "effort" as a barrier to short bouts, "health" as a barrier to long bouts.

In combination the results of these three studies demonstrate that a regular walking exercise programme comprising brisk or aerobic walking for a minimum of six weeks can improve cardiovascular fitness and lower risk of cardiovascular disease in previously sedentary adults. The same health benefits can still be achieved even if walking pace is slowed to 4.8km/h. When prescribing such an exercise programme, it may be perceived as more physically manageable and easier to integrate into a daily routine if the exercise is introduced via smaller bouts.

Chapter 3: WALKING, THE SCIENCE

3.1. The biomechanics of walking

During human walking, whole-body angular momentum is kept remarkably close to zero, an indication of significant segment-to-segment cancellation (Herr & Popovic, 2008). In particular, since the arms swing out of phase with the legs, the arm moments serve to cancel lower limb moments about the vertical axis. That is, the naturally occurring arm swing during walking acts as a mass damper, decreasing the amplitude of upper body rotation brought about by the swinging action of the legs (Pontzer, Holloway, Raichlen & Lieberman, 2009).

Initially it was thought that arm swing was driven by muscle activity in the shoulders, simultaneously creating upper body rotation in opposition to that produced by the legs and pelvis during walking. This active arm swing model, in which additional energy would be expended to limit twisting of the torso, has been challenged by several authors.

During normal walking Pontzer et al. (2009) observed a shoulder muscle activation pattern completely at odds with the active model. Rather than the anterior deltoid firing as the arm is swung forward and the posterior deltoid firing as the arm is swung backwards, the two muscles are activated simultaneously, suggesting their role is to stabilise the arm and shoulder rather than drive the arm swing. Figures 3.1a,b compare the muscle activity in the shoulder during active arm pumping and normal walking.

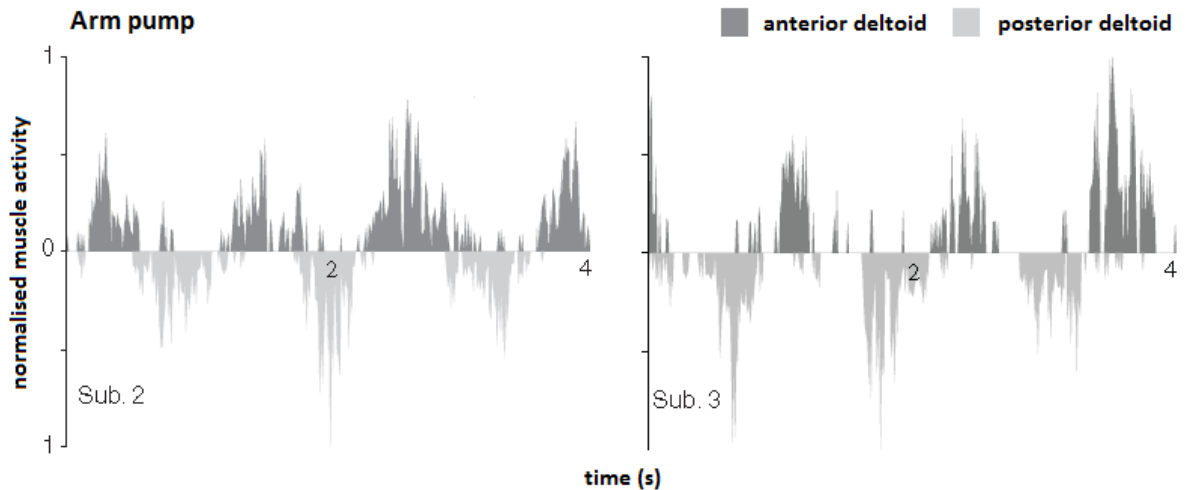


Figure 3.1a: Activity of the anterior and posterior deltoid muscles during arm pumping in two subjects.
(Adapted from Pontzer et al., 2009)

The authors concluded that the upper body movement, specifically the arm swing, is driven by movement in the legs and pelvis, with forces transferred to the shoulders and arms via ligaments and muscles in the spine acting as springs. Rather than impart any energy into the system to decrease movement in the torso, the arms act as auxiliary masses which passively dampen movement in the torso (the principal mass) to produce stable walking.

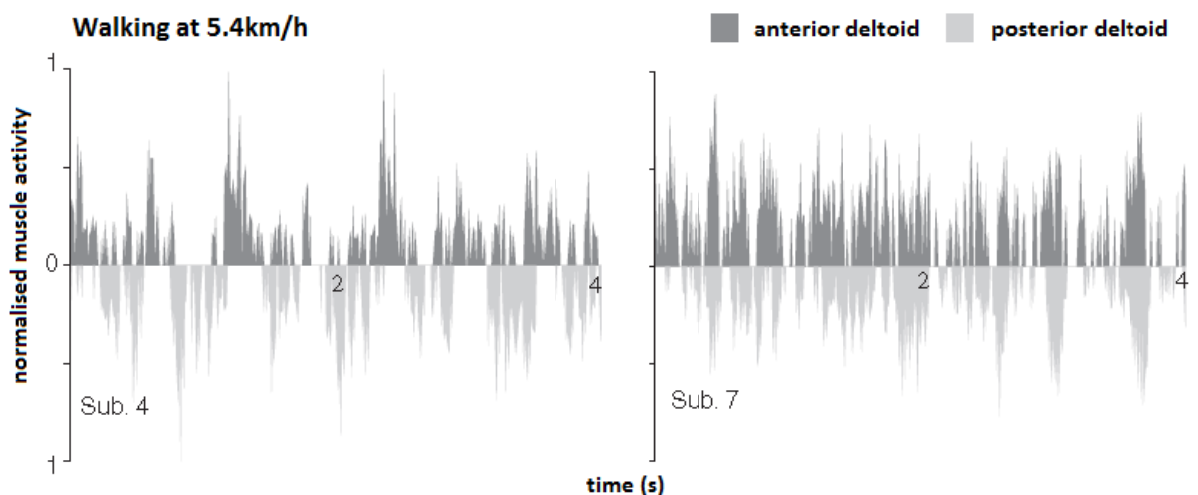


Figure 3.1b: Activity of the anterior and posterior deltoid muscles during normal walking at 5.4km/h in two subjects.
(Adapted from Pontzer et al., 2009)

To give further credence to this model, Pontzer et al. (2009) instructed ten subjects to walk at a speed of 5.4km/h, first normally and then with their arms folded tightly across their chest. The latter demanded an 8.3% increase in the metabolic cost of locomotion; $11.7 \pm 2.7 \text{ ml/kg/min}$ compared with $10.8 \pm 1.8 \text{ ml/kg/min}$. While this result was not significant ($p=0.10$), this increase translates into an additional expenditure of 0.27kcal/kg/h of walking, that is 16kcal/h for a person weighing 60kg.

In a similar study (Collins, Adamczyk & Kuo, 2009) a mean net metabolic rate of $3.09 \pm 0.12 \text{ W/kg}$ was recorded when ten subjects walked at 4.5km/h. This figure rose by 7% to $3.31 \pm 0.22 \text{ W/kg}$ when arms were bound at the side ($p<0.05$), and by 12% to $3.45 \pm 0.25 \text{ W/kg}$ when arms were held at the side ($p<0.05$).

The results of these studies and others are compared in Table 3.1. With the exception of Pontzer et al. (2009), all studies found a statistically significant increase of 5-12% in the net metabolic cost of walking when arm swing was prevented, equating to between 6-19kcal/h for a person of 60kg.

Table: 3.1: Net metabolic cost of walking normally vs walking without arm swing. (Results obtained from the literature sources listed)

Research study	speed (km/h)	normal walking (ml/kg/min)	without arm swing (ml/kg/min)	arm position	increase (%)	p value
Collins et al., 2009 ¹	4.50	8.75	9.37	bound at side	7.1	< 0.05
	4.50	8.75	9.77	held at side	11.7	< 0.05
Ortega, Fehlman & Farley, 2008 ²	4.68	7.28	7.62	folded	4.7	0.004
	4.68	8.38	8.89	folded	6.1	0.004
Umberger, 2008	5.40	8.07	8.69	folded	7.7	0.004
Pontzer et al., 2009	5.40	10.80	11.70	folded	8.3	0.100

1: $\text{W/kg} \rightarrow \text{ml/kg/min}$: $(3.09 \times 0.0143 \text{ kcal/min}) / 5.05 \text{ kcal} \times 1,000 = 8.75 \text{ ml/kg/min}$, 2: young and elderly populations, respectively

Simulations and human experiments performed by Collins et al. (2009) led the authors to agree with Pontzer et al. (2009), that arm swing is the result of passive dynamics and requires minimal effort. Furthermore, for that minimal effort the arm swing

appears to provide a benefit in the form an overall net reduction in metabolic cost of walking; the human body striving for efficiency.

From a biomechanical standpoint, how is this metabolic benefit of arm swing derived? When a subject steps on the ground he or she exerts a force that is generally downward and backward in direction. In accordance with Newton's third law of motion, the ground reacts by exerting an equal and opposite force on the subject at the contact point that is generally upward and forward; referred to as the ground reaction force (Tongen & Wunderlich, 2010).

The vertical moment of this force is transmitted upwards from the foot, through the leg to the pelvis, and is resisted by internal joint reaction moments produced by the leg muscles at various stages of the gait cycle. This resistance requires energy expenditure, and Collins et al. (2009) suggest the presence of arm swing reduces the need for the leg muscles to produce torques that resist the vertical moment of the ground reaction force.

Hence the small additional metabolic cost incurred by the deltoid muscles in stabilising the arms and shoulders during arm swing brings about a 5-12% reduction in the whole-body metabolic cost of walking by reducing the demands placed on the leg muscles. Conversely, when arm swing is prevented, the muscles of the lower limbs are required to work harder in resisting the vertical ground reaction moment.

At normal walking speeds the cost-benefit balance of a near passive arm swing, (i) close to zero angular momentum and (ii) reduced vertical ground reaction moments, suggests that humans naturally seek the most economical gait. In simulation, Collins et al. (2009) found that when walking at higher speeds arm swing becomes active rather than passive. The direct energy cost associated with arm swing would therefore increase with walking speed, but the authors speculated that the indirect benefits of

reduced vertical moments would increase as well; larger arm movements cancelling the larger effects of faster, more powerful leg motions.

3.1.1. The function and impact of vigorous arm swing

To intensify walking exercise there are several options for the walker; increase speed (Ainsworth et al., 2011), increase gradient (Graves, Pollock, Montain, Jackson & O’Keefe, 1987; Graves, Martin, Miltenberger & Pollock, 1988), walk on less stable surfaces such as sand (Lejeune, Willems & Heglund, 1998), carry additional weight (Auble & Schwartz, 1991), or any combination.

Increasing walking pace from a steady stroll to a brisk walk to a power/aerobic walk will transform a moderate-intensity exercise to a vigorous one (>6.0METs) at approximately 6.9km/h. Using data provided by Ainsworth et al. (2011), Figure 3.2 shows the metabolic cost of walking at various speeds, assuming a level, firm surface.

At low speeds (3-5km/h) the relationship between walking speed and metabolic cost is approximately linear (ACSM, 2009). However, at speeds greater than 5km/h the curvilinear shape becomes more pronounced. This variation in shape between low and high speeds is frequently, but possibly erroneously, attributed to the more vigorous arm swing which typically occurs when walking at faster pace. Indeed the findings of Collins et al. (2009) suggest that this graph would be more convex if it were not for the energetic cost-benefit balance of arm swing in reducing vertical ground reaction moments.

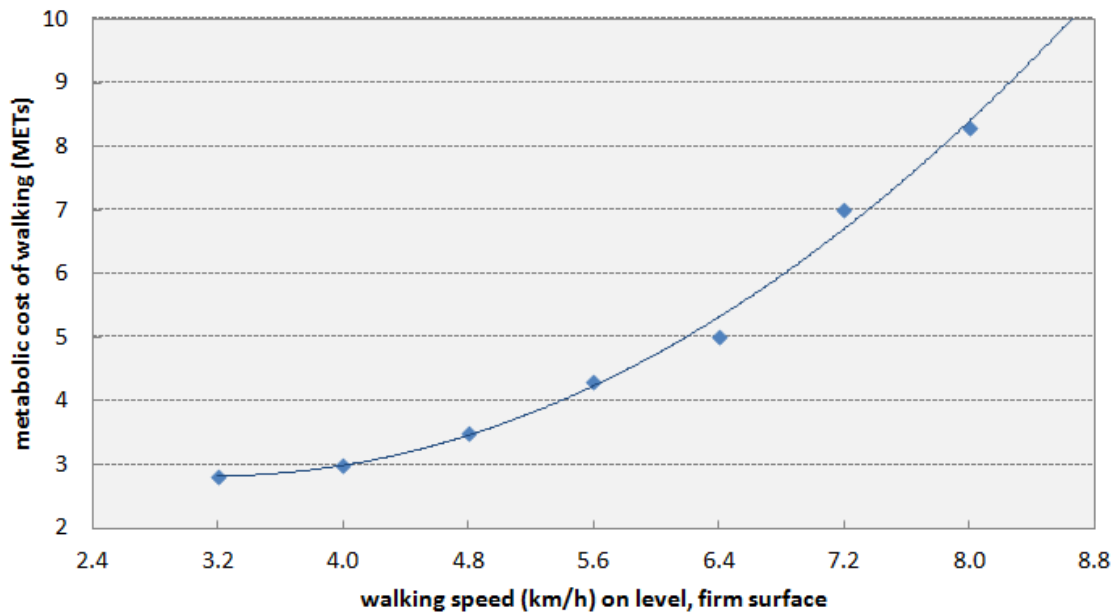


Figure 3.2: Metabolic cost of walking at various speeds on a level, firm surface.
(Data obtained from Ainsworth et al., 2011)

Earlier work by Maud, Stokes and Stokes (1990), provides evidence of other ways in which vigorous arm swing can promote a more energy efficient gait. To investigate the contribution of arm swing in weighted and unweighted walking at 6.4km/h on a level treadmill, subjects (10 men, 10 women) were observed under four conditions:

1. walking normally (natural arm swing)
2. walking normally while carrying 1.36kg hand-held weights
3. walking with a vigorous arm swing
4. walking with a vigorous arm swing while carrying 1.36kg hand-held weights (HWs).

When employing a vigorous arm swing subjects were required to raise the hand above shoulder level on the forward swing, a 90° angle at the elbow, and take it just past the buttock on the back swing, a 170° angle at the elbow (Figure 3.3).

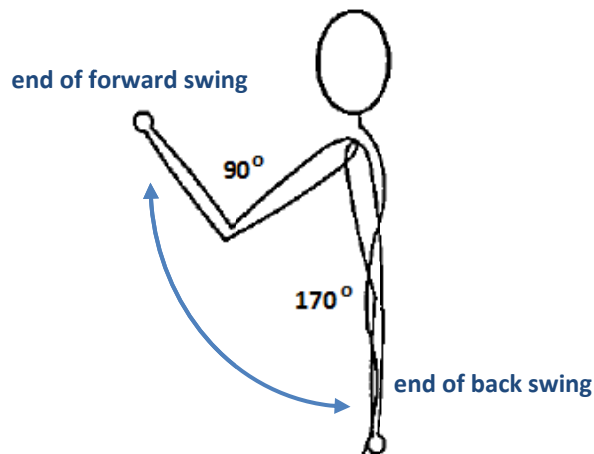


Figure 3.3: Vigorous arm swing instructed by Maud et al., 1990.

When comparing the energy cost of the two unweighted conditions, the authors observed a 10% increase in mean oxygen uptake when vigorous arm swing was applied. The rise from 20.1ml/kg/min to 22.1ml/kg/min was significant ($p < 0.01$; Figure 3.5) and independent of gender.

On closer examination, the difference in energy cost between the two forms of unweighted exercise was not accounted for by the inclusion of upper body exercise alone. Concomitant with an increased movement of the arms, subjects lengthened stride and hence decreased the average number of strides taken per minute; from 63.1 ± 2.5 strides/min walking with a normal arm swing to 61.6 ± 2.7 strides/min assisted by a vigorous arm swing. The authors speculated that the increased energy cost was in part due to the increased stride length, but is this necessarily the case?

Morgan and Martin (1986) examined the impact of varying stride length on oxygen uptake in seven competitive walkers of varying abilities. A subject's freely-chosen stride length (FCSL) was first established while walking at a speed appropriate to his/her aerobic fitness level (7.6km/h, 8.8km/h or 11.4km/h). Maintaining the same speed, subjects were then required to complete five 6min walks at varying stride lengths indicated by a metronome; FCSL, $\pm 5\%$ of leg length from FCSL, and $\pm 10\%$ of leg length from FCSL. The order of the stride lengths was randomly assigned and $\dot{V}O_2$ measured during the last 2min of each walk.

Figure 3.4 shows the variation in group mean $\dot{V}O_2$ as stride length was modified. Although there was some variation amongst subjects, the group statistics suggest that the walkers typically selected close to the most economical stride length as their FCSL. Furthermore, a stride length significantly different from the FCSL was (i) difficult to maintain, demonstrated by the tendency to walk at a stride length closer to the FCSL than that specified, and (ii) energetically more demanding.

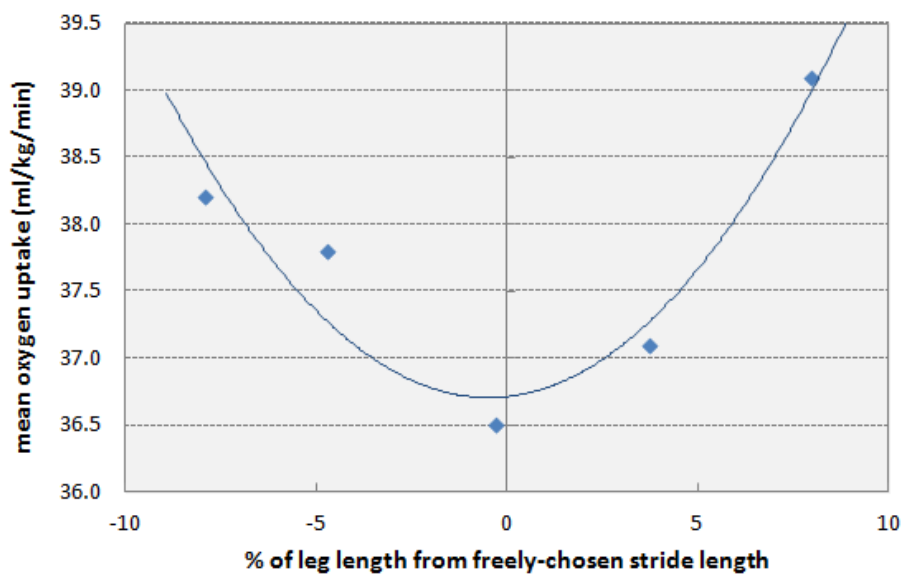


Figure 3.4: Variation in group mean oxygen uptake as stride length is modified. Values are plotted against actual stride length observed.
(Data obtained from Morgan & Martin, 1986)

Although Maud et al. (1990) did not study the behaviour of competitive walkers, their subjects were physically active and participated in aerobic activities at least three times per week. The results of Morgan and Martin (1986) suggest that the adjustment in stride length between walking normally and walking with a vigorous arm swing may have been made in order to attain the most economical gait under the more demanding conditions. Indeed a reduction in the number of exercise reps completed each minute would in isolation have an energy-conserving effect.

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To quantify this effect it is useful to consider oxygen uptake per step taken; one stride equal to two steps. During normal walking the oxygen uptake was 0.159ml/kg/step, and when a vigorous arm swing was added it became 0.179ml/kg/step:

$$20.1 \div (2 \times 63.1) = 0.159\text{ml/kg/step}$$

$$22.1 \div (2 \times 61.6) = 0.179\text{ml/kg/step}$$

Had there not been (on average) a reduction of three steps per minute when the vigorous arm swing was introduced, the oxygen uptake would have risen even more to 22.6ml/kg/min.

$$(2 \times 63.1) \times 0.179 = 22.6\text{ml/kg/min}$$

This oxygen uptake is 12.5% greater than the 20.1ml/kg/min observed during normal walking at 6.4km/h.

Although not demonstrated directly in the work of Maud et al. (1990), the interaction between arm swing and stride frequency, which appears to take place in an attempt to achieve walking efficiency, could be limiting the amount by which the energy cost of walking increases with increasing speed. The natural tendency for humans to employ a more vigorous arm swing as walking speed is increased may limit the amount by which the exercise demands greater work. The reduction in vertical ground reaction moment and the increase in stride length might more than compensate for the additional energy cost of the active arm swing. Conversely, the absence of these two mechanisms might otherwise lead to a more curvilinear form in Figure 3.2.

3.2. Walking with hand-held weights; the physiological responses

The work of Maud et al. (1990) is one of nine studies undertaken in the last 30 years to investigate the physiological impact of walking with hand-held weights. Comparisons between walking with or without additional weight has been conducted on a variety of populations, employing a range of different speeds, and using between 0.45kg and 2.27kg per hand. Some studies have used an incline to achieve a target exercise intensity (Graves et al., 1987; Graves et al., 1988), others have specified a particular arm action very different to a normal walking swing (Auble, Schwartz & Robertson, 1987). In each case the authors have anticipated an increase in the energy cost and perceived exertion of the exercise, and expected to observe elevated heart rate and blood pressure as a direct result of the additional weight.

Although there is some agreement in the literature, the lack of homogeneity between studies makes it difficult to perform meta-analysis. However, examination of the collective data does reveal important relationships and possibly unexpected findings, and these are summarised below. Alongside an understanding of the biomechanics of walking, these findings may help to establish a more complete picture of this low-impact but potentially high-intensity exercise and its benefits for certain populations.

Table 3.2: The effect of hand-held weights on energy cost of walking on a treadmill.

(Results obtained from the literature sources listed)

Research study	subjects, exercise status	speed (km/h)	gradient (%)	HW (kg)	arm swing	mean $\dot{V}O_2$ (ml/kg/min)			diff. (%)	p value
						w/o HWs	with HWs	difference		
Francis & Hoobler, 1986	5 men, 5 women, active	4.8	0.0	0.91	normal arm swing with arc ranging from 40 to 50°	12.1	12.9	0.8	7	NS
		5.6	0.0	0.91		16.0	16.7	0.7	4	NS
		4.8	0.0	1.81	normal arm swing with arc ranging from 30 to 40°	12.1	13.4	1.3	11	NS
		5.6	0.0	1.81		16.0	17.1	1.1	7	NS
¹Auble et al., 1987	9 men, trained	4.0	0.0	0.45	arm pump = 0.91m	10.9	17.5	6.6	61	p < 0.05
		4.0	0.0	1.36	arm pump = 0.91m	10.9	20.8	9.9	91	p < 0.05
		4.8	0.0	0.45	arm pump = 0.91m	14.1	20.0	5.9	42	p < 0.05
		4.8	0.0	0.91	arm pump; 0.61, 0.76, 0.91, 1.07m	14.1	18.4 - 29.2	4.3 - 15.1	30 - 107	p < 0.05
		4.8	0.0	1.36	arm pump = 0.91m	14.1	24.9	10.8	77	p < 0.05
		5.6	0.0	0.45	arm pump; 0.61, 0.91, 1.07m	16.5	20.1 - 31.5	3.6 - 15.0	22 - 91	p < 0.05
		5.6	0.0	0.91	arm pump; 0.61, 1.07m	16.5	21.6 - 36.2	5.1 - 19.7	31 - 119	p < 0.05
		5.6	0.0	1.36	arm pump; 0.61, 0.91, 1.07m	16.5	23.5 - 42.0	7.0 - 25.5	42 - 155	p < 0.05
		6.4	0.0	0.45	arm pump = 0.91m	20.0	29.2	9.2	46	p < 0.05
		6.4	0.0	0.91	arm pump; 0.61, 0.76, 0.91, 1.07m	20.0	27 - 42.7	7.2 - 22.7	36 - 114	p < 0.05
		6.4	0.0	1.36	arm pump = 0.91m	20.0	36.6	16.6	83	p < 0.05

Table 3.2: The effect of hand-held weights on energy cost of walking on a treadmill. /cont.

(Results obtained from the literature sources listed)

Research study	subjects, exercise status	speed (km/h)	gradient (%)	HW (kg)	arm swing	mean $\dot{V}O_2$ (ml/kg/min)			diff. (%)	p value
						w/o HWs	with HWs	difference		
Miller & Stamford, 1987	4 male, 3 female college students, active	3.2	0.0	2.25	swing arm from shoulder and move HWs in arc from umbilicus to sternoclavicular joint, maintaining 90° angle at elbow	7.3	13.0	5.7	78	p < 0.05
		4.8	0.0	2.25		10.6	17.7	7.1	67	p < 0.05
		6.4	0.0	2.25		18.7	25.1	6.4	34	p < 0.05
² Graves et al., 1987	12 men, sedentary	5.9	7.9	0.45	lift HWs to shoulder height on each swing and maintain 90° angle at elbow when HWs were at shoulder height	25.3	27.2	1.9	8	p < 0.01
		5.9	10.5	0.45		29.4	31.1	1.7	6	p < 0.01
		5.9	7.9	1.36		25.3	28.6	3.3	13	p < 0.01
		5.9	10.5	1.36		29.4	32.5	3.1	11	p < 0.01
³ Graves et al., 1988	12 men, sedentary	6.3	6.3	1.36	lift HWs to shoulder height on each swing and maintain 90° angle at elbow throughout motion	26.6	30.4	3.8	14	p < 0.01
Owens et al., 1989	10 male students, active	4.8	0.0	0.45	normal arm swing	n/a	n/a	-	-	NS
		6.4	0.0	0.45		n/a	n/a	-	-	NS
		4.8	0.0	1.36		n/a	n/a	-	-	NS
		6.4	0.0	1.36		n/a	n/a	-	-	NS
		4.8	0.0	2.27		n/a	n/a	-	-	NS
		6.4	0.0	2.27		n/a	n/a	-	-	NS

Table 3.2: The effect of hand-held weights on energy cost of walking on a treadmill. /cont.

(Results obtained from the literature sources listed)

Research study	subjects, exercise status	speed (km/h)	gradient (%)	HW (kg)	arm swing	mean $\dot{V}O_2$ (ml/kg/min)			diff. (%)	p value
						w/o HWs	with HWs	difference		
Maud et al., 1990	10 men, 10 women, active	6.4	0.0	1.36	normal arm swing	20.1	21.1	1.0	5	NS
		6.4	0.0	1.36	hand to rise above shoulder level (90° angle at elbow) and past buttock on back swing (170° angle at elbow)	20.1	26.8	6.7	33	p < 0.01
⁴ Morrow et al., 1992	18 women, active	6.3	0.0	0.45	pumping weights to height of 0.30m	19.4	19.5	0.1	1	NS
		6.1	0.0	1.36		19.4	19.9	0.5	3	NS
⁵ Evans et al., 1994	19 older adults, active, regular walkers	3.2 - 7.2	0.0	0.45	normal arm swing with elbows at 90° angle	13.2	13.8	0.6	5	NS
		3.2 - 7.2	0.0	1.36		13.2	15.7	2.5	19	p < 0.05
		3.2 - 7.2	0.0	2.27		13.2	15.7	2.5	19	p < 0.05

NS denotes “not significant”.

1: The arm pumping action employed in the study by Auble et al., 1987 started with the arm extended by the side of the body. The elbow was first flexed until the HW was approximately shoulder height, then the hand raised vertically to a position almost directly above the head (the arm pump). The arm pump was terminated at four heights; 0.61m, 0.76m, 0.91m, 1.07m. (Data is approximate in places, having been read from a graph.)

2: Speed and gradient were reported as mean (5.9 ± 0.2 km/h, $7.9 \pm 1.8\%$, $10.5 \pm 2.4\%$), selected to achieve 60% and 75% heart rate reserve for each subject.

3: Speed and gradient were reported as mean (6.3 ± 0.25 km/h, $6.3 \pm 1.4\%$), selected to achieve 60% heart rate reserve for each subject.

4: Subjects walked at a self-selected pace for each of three different exercise modes; no weight, 0.45kg, 1.36kg. The mean pace was 6.4km/h when no weight was carried.

5: Speed of 3.2-7.2km/h was constant self-selected walking speed which felt like normal exercise pace.

Table 3.3: Imperial to metric conversion of commercially available hand-held weights.

weight (lb)	1	2	3	4	5
weight (kg)	0.45	0.91	1.81	1.36	2.27

3.2.1. Energy cost of weighted walking

The effects of hand-held weights on the metabolic cost of walking are summarised in Table 3.2. Two patterns emerge from the collective data; (i) that arm swing appears to have significant bearing on the intensity of the exercise when using hand-held weights, and (ii) the heavier the weight added, the greater the increase in energetic cost.

Irrespective of weight added, Francis and Hoobler (1986), Owens, Al-Ahmed and Moffatt (1989), Maud et al. (1990), Morrow, Bishop and Ketter (1992) reported no significant difference in the metabolic cost of walking when normal arm swing was employed, i.e. the weight was moved through a limited vertical distance. Weights ranging from 0.91kg to 1.81kg produced only small and insignificant increases in $\dot{V}O_2$ of 0.7-1.3ml/kg/min when compared to unweighted walking at strictly the same pace.

Maud et al. (1990) drew comparisons between weighted and unweighted walking at 6.4km/h, employing both a normal and vigorous (Figure 3.3) arm swing. Walking unweighted with normal arm swing required a mean oxygen uptake of 20.1 ± 1.9 ml/kg/min. Adding 1.36kg weights to this arm swing produced only a 1ml/kg/min increase in $\dot{V}O_2$, whereas adding an unweighted vigorous arm swing produced a significant increase of 2ml/kg/min ($p < 0.01$). When 1.36kg weights and a vigorous arm swing were added to the exercise simultaneously, the authors observed a mean oxygen uptake of 26.8 ± 3.1 ml/kg/min, 33% more demanding than unweighted normal walking (Figure 3.5).

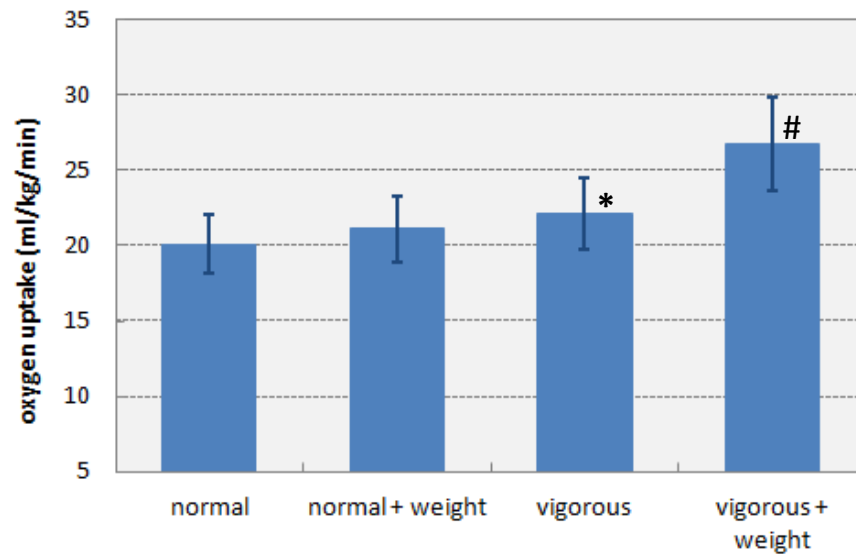


Figure 3.5: Mean (\pm SD) oxygen uptake during four walking conditions; walking normally, walking normally carrying 1.36kg HWs, walking with a vigorous arm swing, walking with a vigorous arm swing carrying 1.36kg HWs, all at 6.4km/h. *significant difference vs normal; #significant difference vs normal, normal + weight, vigorous (all $p < 0.01$). (Adapted from Maud et al., 1990)

These results suggest the impact of hand-held weights is related to the arm swing used. Looking for agreement between these and the findings of others is challenging since varying degrees of arm swing are used. Auble et al. (1987), Miller and Stamford (1987), Maud et al. (1990) and Morrow et al. (1992) all published data for trained subjects walking at 6.4km/h, albeit the mean self-selected pace in the case of the latter study.

Auble et al. (1987) and Maud et al. (1990) specified a “vigorous” arm swing involving flexion at the elbow and the weight travelling through a vertical distance of at least 0.60m. Miller and Stamford (1987) described their arm swing as “vigorous but not excessive”, an action similar to that of Morrow et al. (1992), which will be referred to as “active” being more so than a normal arm swing (Figure 3.6).

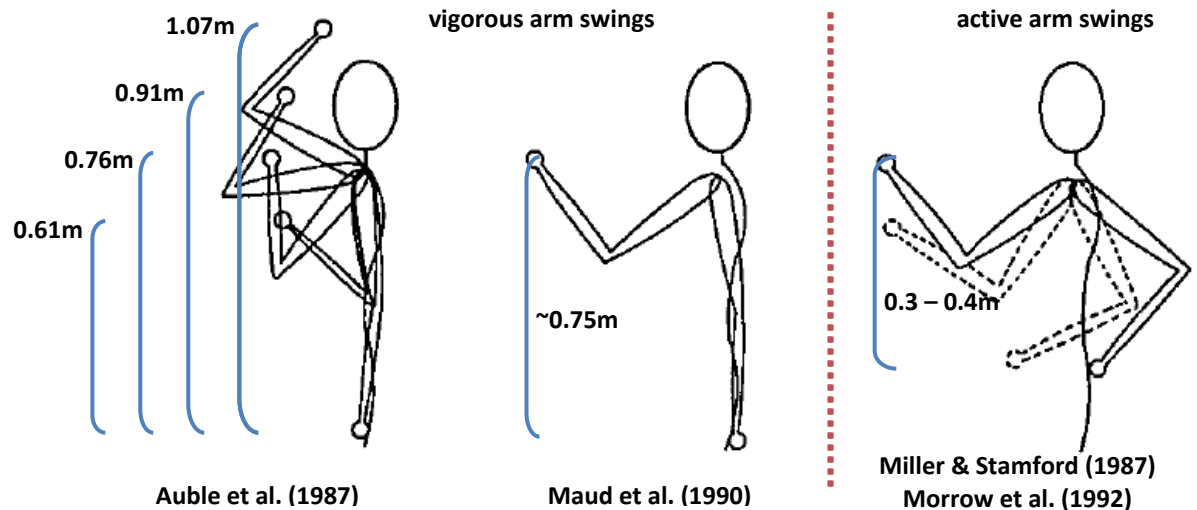


Figure 3.6: Arm swing used during weighted walking in the four studies listed.

Figure 3.7 shows oxygen uptake plotted against weight added across all four studies, taking into account the classification of the arm swing. With the exception of Maud et al. (1990) who also observed the impact of a vigorous but unweighted arm swing, the arms were swung normally when subjects were not carrying weights. Normal walking demanded a mean 19.7ml/kg/min of oxygen when data from the four studies were combined.

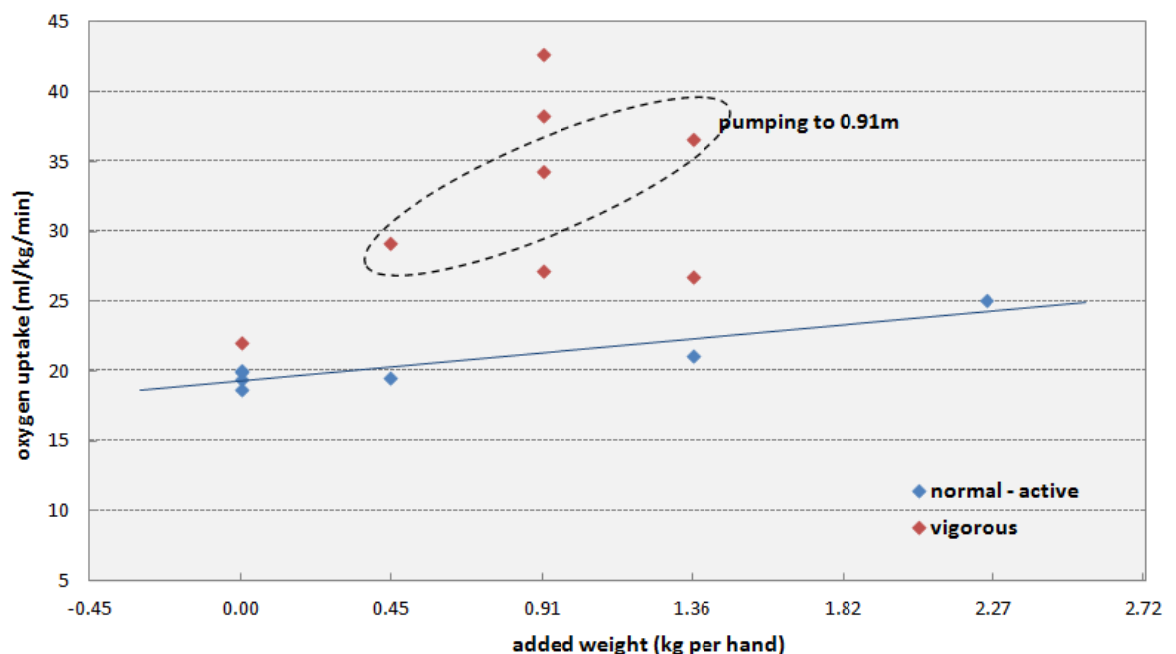


Figure 3.7: Mean oxygen uptake vs added weight (per hand) during unweighted and weighted walking at 6.4km/h in which either an active or vigorous arm swing was used. (Results taken from Auble et al., 1990; Maud et al., 1990; Miller & Stamford, 1987; Morrow et al., 1992)

Carrying weight with an active arm swing does increase the metabolic cost of walking, the degree to which it does being a function of the weight carried. If the walking speed is held constant at 6.4km/h, the relationship between mean oxygen uptake and added weight w (kg per hand) can be approximated by the linear equation

$$\dot{V}O_2 \text{ (ml/kg/min)} = 2.2026w + 19.28, \text{ with } R^2 = 0.844 \text{ (} p=0.003 \text{)} \quad \text{Eq. 3.1}$$

That is, with every 0.45kg (1lb) of weight added per hand, the metabolic cost of walking at 6.4km/h increases by 1.0ml/kg/min if an active arm swing is used.

While Miller and Stamford (1987) and Morrow et al. (1992) demanded that the elbow remain flexed at 90° throughout, the vigorous arm swings of Auble et al. (1987) and Maud et al. (1990) were more complex, involving both flexion at the elbow and rotation at the shoulder. As a consequence the weight was displaced through a greater vertical distance which further increased the oxygen cost of the exercise. Of the two, the arm movement used by Auble et al. (1987) was less efficient since it did not take advantage of angular momentum as the elbow was flexed, and required subjects to pump the weight to one of four different heights (Figure 3.6). The increased upper body muscle involvement undoubtedly led to a greater energy cost (Figure 3.7).

It is difficult to perform regression analysis on the “vigorous” data, although the trend remains clear; as the added weight increases, all other things remaining equal, the energy cost of the exercise increases.

3.2.2. Rating of perceived exertion

Perceived exertion during exercise is a subjective measure of the impact a series of signals has on the psychological and physical wellbeing of the exercising person; the signals being of effort, stress and fatigue received from the peripheral working muscles and joints, and the cardiopulmonary system (Borg, 1982). Perceived exertion can be

rated using the Borg Scale, a scale running from 6 to 20 which is strongly correlated ($R>0.8$) to objective measures of exercise intensity, including heart rate, oxygen consumption and power output (Borg, 1962). Rating of perceived exertion (RPE) was recorded in six of the studies listed in Table 3.2.

Graves et al. (1987) asked 12 sedentary subjects to first walk at 60% and 75% of their previously established heart rate reserve (HRR), these target intensities reached by altering both treadmill speed and incline. While adding weights of 0.45kg did increase the energy cost by 6-8% (Table 3.2), no significant increase in RPE was recorded. In fact there was a small statistically insignificant decline of 0.6pts in the case of 60%HRR. However, when 1.36kg were added, both mean $\dot{V}O_2$ and RPE increased significantly ($p<0.01$); the 3.3ml/kg/min increase in $\dot{V}O_2$ was matched with a rise of 1.3pts in mean RPE when subjects began exercising at 60%HRR, the 3.1ml/kg/min increase in $\dot{V}O_2$ was matched with a rise of 1pt in mean RPE when subjects began at 75%HRR. All weighted exercise was conducted with an active arm swing.

In a similar study involving sedentary subjects initially exercising at 60%HRR, Graves et al. (1988) reported a 3.8ml/kg/min increase in $\dot{V}O_2$ when 1.36kg were added to each hand ($p<0.01$). However, this was not accompanied by a significant increase in RPE, which remained in the range 11.7-12.3 irrespective of whether subjects walked with or without hand-held weights. Again, an active arm swing was used.

Owens et al. (1987) reported no significant increases in both $\dot{V}O_2$ and RPE when weights of 0.45, 1.36 and 2.27kg were added to walking speeds of 4.8 and 6.4km/h, normal arm swing maintained.

Maud et al. (1990) observed no significant difference in $\dot{V}O_2$ or RPE when 1.36kg weights were added to walking exercise at 6.4km/h using a normal arm swing. When a vigorous but unweighted arm swing was added $\dot{V}O_2$ increased significantly by 2ml/kg/min ($p<0.01$) (Figure 3.5), but RPE remained unchanged. Only when weight

was added using a vigorous arm swing did significant increases occur in both $\dot{V}O_2$ (6.7ml/kg/min, 33%) and RPE (3.5pts, 38%), ($p<0.01$). A similar pattern emerged when data was considered by gender.

When 19 subjects, regular walkers of ≥ 55 yrs, were allowed to select their usual walking pace (Evans, Potteiger, Bray & Tuttle, 1994) they exercised with a mean $\dot{V}O_2$ of 13.2 ± 4.6 ml/kg/min and rated their level of exertion to be 10 ± 2 on the Borg Scale. The changes in $\dot{V}O_2$ and RPE which occurred following the addition of 0.45, 1.36 and 2.27kg to the exercise are shown in Figure 3.8.

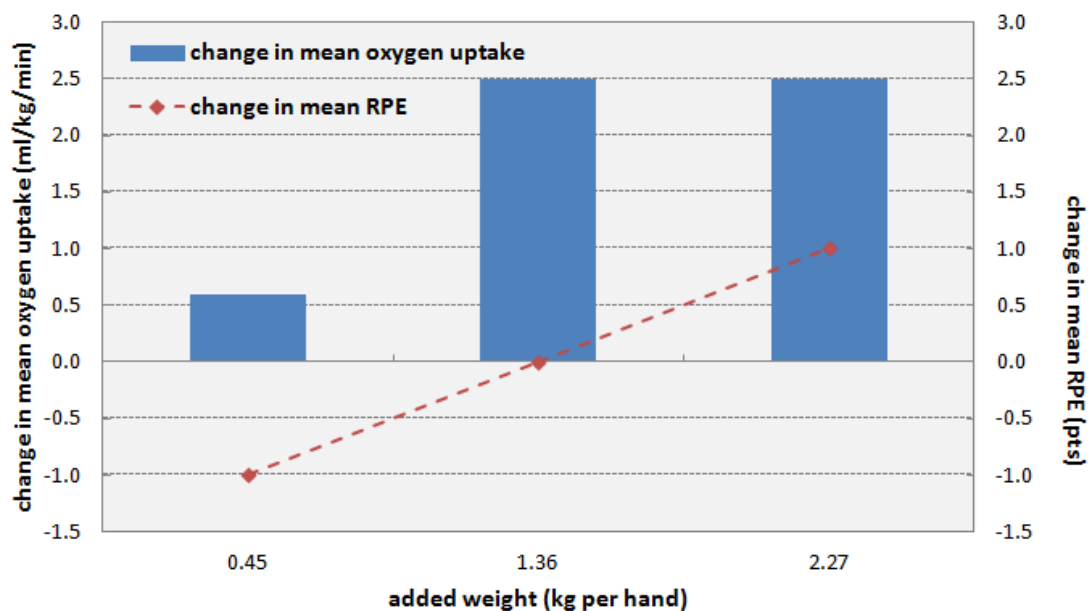


Figure 3.8: Change in mean oxygen uptake and RPE when hand-held weights were added to walking exercise at constant speed of 6.4km/h in older subjects, ≥ 55 yrs. (Adapted from Evans et al., 1994)

It is immediately evident from this data that, for these regular walkers, adding weight was not necessarily perceived to be more energetically demanding, even if physiologically it was. With the smaller weights mean RPE declined, albeit insignificantly, from 10 ± 2 to 9 ± 2 while $\dot{V}O_2$ rose by a small and insignificant amount. When 1.36kg weights were added, mean RPE was unchanged at 10 ± 2 while mean $\dot{V}O_2$ rose significantly to 15.7 ± 4.7 ml/kg/min ($p<0.05$). The addition of 2.27kg saw no further increase in mean oxygen uptake but the first significant increase in mean RPE; a rise of 1pt to 11 ± 3 .

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Morrow et al. (1992) allowed 18 physically active women to select a walking speed they felt they could maintain for 20min in each of three exercise scenarios; unweighted, walking with 0.45kg weights, walking with 1.36kg weights. While speed declined significantly ($p<0.05$) with each increase in weight (Table 3.4), mean $\dot{V}O_2$ remained consistent at 19.4-19.9ml/kg/min. With the addition of 0.45kg, RPE declined by 0.7pts ($p>0.05$); oxygen uptake had not declined but the perception was the work was marginally less demanding. It was not until the heavier weight of 1.36kg was added that RPE changed significantly, rising from 13.9 ± 3.0 to 14.3 ± 3.1 ($p<0.05$), although still within one point on the scale.

Table 3.4: Group means (\pm SD) of physiological variables and walking speed with 0, 0.45, 1.36kg hand-held weights (N=18). (Adapted from Morrow et al., 1994)

HW (kg)	speed (km/h)	$\dot{V}O_2$ (ml/kg/min)	RPE
0.00	6.4 ± 0.7^a	19.4 ± 4.6^a	13.9 ± 3.0^a
0.45	6.3 ± 0.7^b	19.5 ± 0.7^a	13.2 ± 2.8^a
1.36	6.1 ± 0.7^c	19.9 ± 0.7^a	14.3 ± 3.1^c

^{a - c} Matching superscripts indicate no significant difference between two conditions in the same column. Varying subscripts indicate significant difference ($p<0.05$) between two conditions in the same column.

Summarising the results of these studies, there appears to be a tendency to tolerate combined arm and leg exercise more readily than leg-only exercise, certainly when the weight added to the upper body does not exceed 1.36kg and a normal to active arm swing is used. The sense of relative ease during combined arm and leg exercise has been attributed to spreading the metabolic workload across a greater muscle mass when compared to leg-only exercise, thereby reducing the metabolic demand placed on any one muscle group (Butt, Knox & Foley, 1995). The added weight and arm swing may be reducing the demands placed on the lower limb muscles to resist the vertical ground reaction moment, leading to a perception of a reduction in workload.

3.2.3. Heart rate and blood pressure response

Two approaches to assessing heart rate (HR) and BP response have been taken in the literature:

1. walking at constant speed with and without hand-held weights
2. walking at a target HR with and without hand-held weights, achieved by altering treadmill speed and/or incline.

Results taken from four studies and obtained using the former approach collectively show a high correlation (Spearman's $\rho=0.933$, $p<0.001$) between the degree by which HR rate is further elevated when hand-held weights are added and the corresponding increase in $\dot{V}O_2$ (Figure 3.9). Walking speeds ranged from 5.9-6.4km/h.

Evidence presented by Miller and Stamford (1987) and Maud et al. (1990) indicates that walking on a level surface at 6.4km/h can be elevated to an intensity sufficient to increase cardiovascular fitness by adding hand-held weights to the exercise, even within physically active populations. When 2.25kg weights were carried with an active arm swing by seven college students, mean HR increased by 23% from 118bpm to 145bpm ($p<0.05$), exceeding the threshold of 60%HRR (75%HR_{max}) (Miller & Stamford, 1987). When 20 regular exercisers of similar mean age carried 1.36kg weights while swinging their arms vigorously, Maud et al. (1990) observed an increase of 21% in mean HR from 119 ± 22 bpm to 144 ± 24 bpm ($p<0.01$). These two results also highlight the trade-off between arm swing and added weight in achieving similar results.

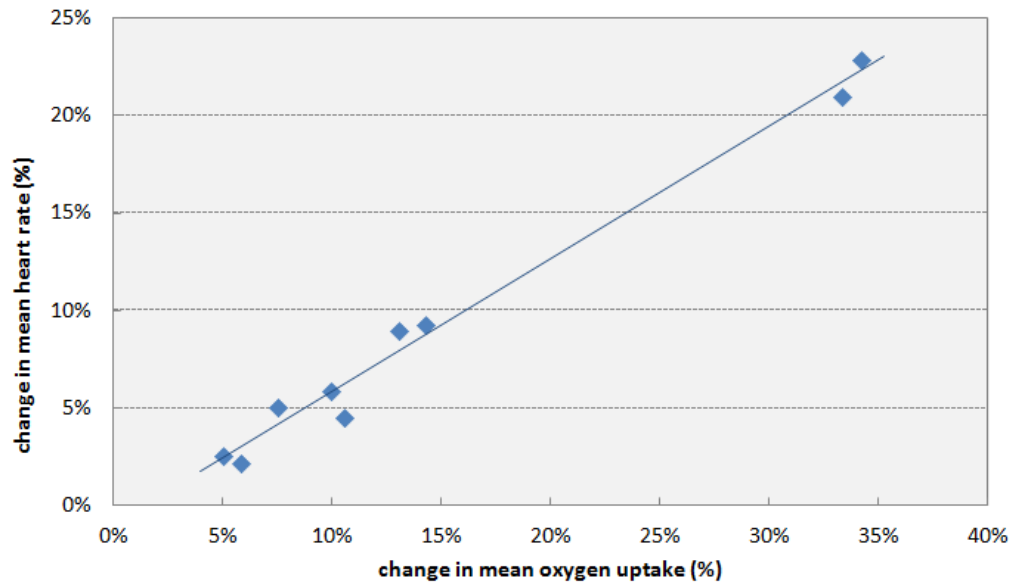


Figure 3.9: Percentage change in mean heart rate vs percentage change in mean oxygen uptake when hand-held weights or vigorous arm swing is added to walking; treadmill speed held constant in the range 5.9-6.4km/h.

(Data taken from Miller & Stamford, 1987; Graves et al., 1987 & 1988; Maud et al., 1990)

Graves et al. (1987 & 1988) adopted the second approach when examining the impact of hand-held weights on BP, using a target HR of 75%HRR in both studies. The 24 subjects, when unweighted, reached and maintained the required exercise intensity by adjusting both speed and incline of the treadmill. After 2min of active recovery, 1.36kg weights and an active arm swing were introduced and the treadmill gradient adjusted to ensure HR did not deviate from the target intensity. Both exercise bouts were undertaken for 8min. In the later of the two studies the process was repeated using 1.36kg wrist and ankle weights.

As expected, the authors observed no difference in mean HR, $\dot{V}O_2$ or RPE between exercise bouts. In the earlier study mean diastolic BP (DBP) was similar but mean SBP was significantly greater during the weighted exercise (160.1 ± 16.9 mmHg) than unweighted exercise (151.1 ± 15.3 mmHg) ($p < 0.01$). In the later study the reverse occurred. While mean SBP was not significantly different between exercises, mean DBP was 4.4 ± 1.2 mmHg greater ($p < 0.05$) during weighted exercise than exercise with no weights. No differences in either measure were observed when wrist or ankle weights were used (Figure 3.10).

Impact of hand-held weights on treadmill walking in previously sedentary women

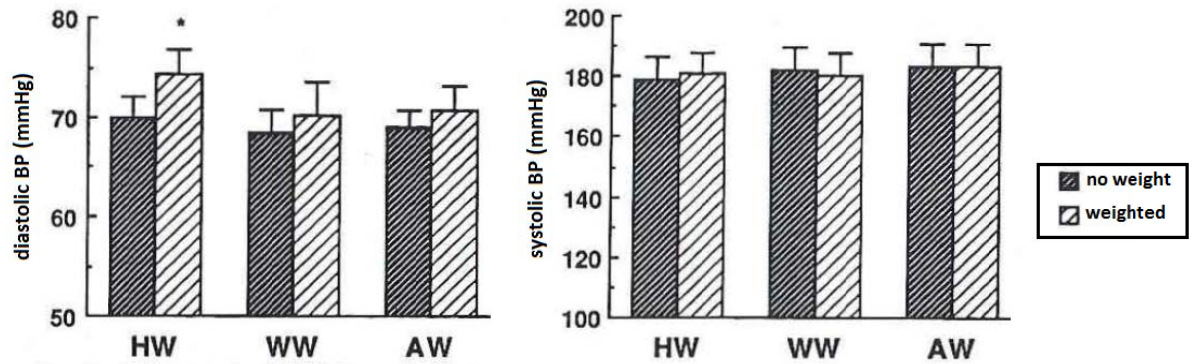


Figure 3.10: Mean (\pm SD) DBP and SBP responses to exercise with HWs, wrist weights (WW) and ankle weights (AW) of 1.36kg compared to exercise without weights (NW) when treadmill grade was adjusted to maintain 75%HRR. *HW>NW ($p<0.05$). (Adapted from Graves et al., 1988)

Evans et al. (1994) used the same approach to examine BP response in 19 regular walkers of ≥ 55 yrs. The target exercise intensity was 70%HRR, maintained by adjusting the speed of a level treadmill. Subjects walked at this intensity for 10min on four occasions, each time carrying a different weight; 0, 0.45, 1.36, 2.27kg. The arm swing was described as normal but subjects were encouraged to maintain a 90° angle at the elbows throughout. Mean and maximal SBP and DBP was measured during the last 5min of each exercise bout.

There was no difference in mean $\dot{V}O_2$ or RPE across the four exercise conditions. The addition of 0.45kg weights did not alter DBP or SBP significantly. Mean DBP increased significantly with the use of 1.36 and 2.27kg weights, while mean SBP changed significantly with only 2.27kg weights (Figure 3.11).

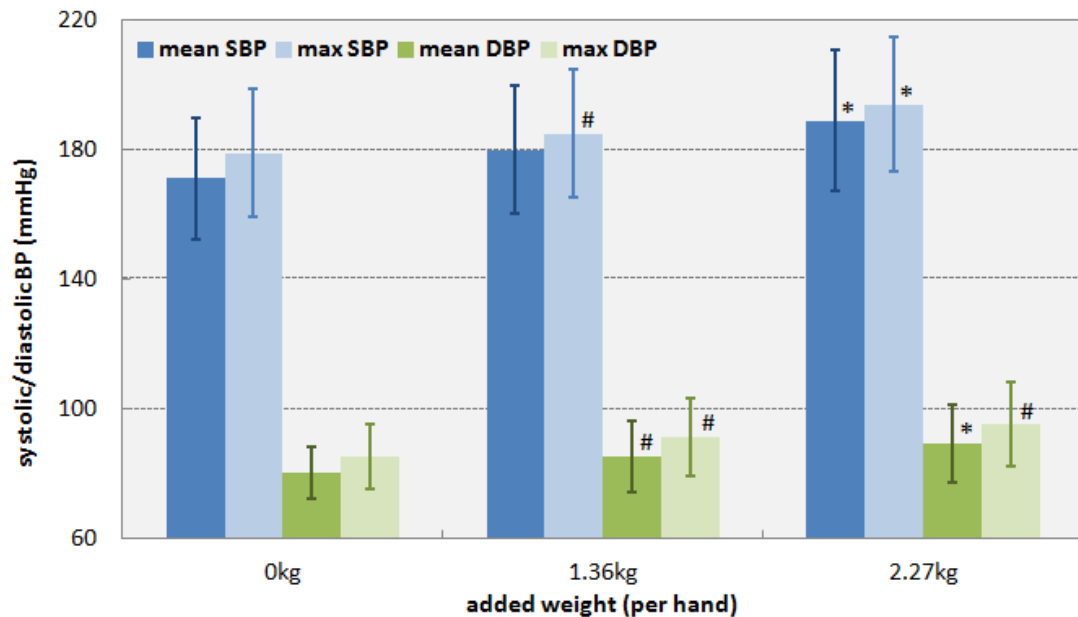


Figure 3.11: Mean and maximal SBP and DBP during last 5min of a 10min exercise bout conducted at 70%HRR while carrying 0, 1.36 and 2.27kg HWs, mean (\pm SD). #significantly greater than walking unweighted; *significantly greater than walking unweighted and walking with 1.36kg weights (all $p \leq 0.05$).

(Data taken from Evans et al., 1994)

The normal response to exercise is a progressive increase in SBP of approximately 10mmHg per 1MET increase in workload, with no change or a decrease in DBP (ACSM, 2009). Given mean $\dot{V}O_2$ did not change significantly when weight was added, the observed increases in SBP (Graves et al., 1987; Evans et al., 1994) and DBP (Graves et al., 1988, Evans et al., 1994) could be regarded as disproportionate and indicative of an elevated total peripheral vascular resistance. Such a response can be induced by (i) an isometric exercise component, (ii) a greater recruitment of fast-twitch motor units, (iii) a greater mechanical compression of the active muscle vasculature, or a combination of all three (Sawka, 1986).

All three studies required subjects to maintain a 90° angle at the elbow when carrying the additional weight. This and a gripping action to hold the weights are isometric contractions and may be accountable for the BP response. Certainly when holding the added weight was not necessary, i.e. in the use of wrist weights (Graves et al., 1988), the significant rise in DBP did not occur (Figure 3.10).

Elbow flexors are known to comprise predominantly fast-twitch muscle fibres, recruitment of which has been linked to the BP response to isometric exercise. This relationship is evidenced in animals (Petrofsky, Phillips, Sawka, Hanpeter, Lind & Stafford, 1981), but has been more difficult to establish in humans (Fisher & White, 2004) due to confounding factors. Therefore it may be the recruitment of fast-twitch muscle fibres when performing the isometric contraction at the elbow that causes the elevated BP.

Exercise performed using a small skeletal muscle mass employs a greater percentage of the muscles' maximal tension to produce a certain power output (Sawka, 1986). This tension may exceed the perfusion pressure and hence increase peripheral resistance within the working muscles. As an illustration, this is thought to cause elevated BP during arm cranking when compared to leg cycle exercise of equivalent power output. However, when subjects walk with hand-held weights the workload of the arms is only a small proportion of the total exercise workload (<20% in the studies considered here) and may not be sufficiently demanding to produce such high intramuscular tension.

Although there is evidence that walking with hand-held weights increases both SBP and DBP even when exercise intensity is held constant, the levels observed in normotensive subjects did not reach those regarded as dangerous; SBP>250mmHg and DBP>115mmHg (ACSM, 2009). It is reasonable to conclude that the moderate rise in BP caused by the addition of weights during walking exercise does not contraindicate their use in such a population.

3.2.4. Physiological adaptations to hand-held weights in exercise

Two studies have examined the effects of hand-held weights on physiological adaptations to exercise, both of them observing these adaptations over an eight-week period. The exercises considered were running and aerobic dance.

Ewing, Vandeputte and Kennon (1987) recruited 20 male runners with mean $\dot{V}O_2\text{max}$ of $52.5 \pm 2.3 \text{ ml/kg/min}$ who ran 32-64km per week. Eight of the subjects added 0.45kg (weeks 1&2), 0.91kg (weeks 3-5) and 1.36kg (weeks 6-8) hand-held weights to their normal running routine, while the others continued as before. Peak torque of the elbow and shoulder flexor and extensor muscles were measured before and after the trial, as well as maximal oxygen uptake. Subjects maintained a daily log of distance run, time taken and perceived exertion.

The authors observed no significant difference between or within groups for either the peak torque measurements or $\dot{V}O_2\text{max}$, concluding that running while carrying light weights was no better stimulus for increasing strength or aerobic capacity than running alone. Moreover, those subjects who carried weights compromised their running speed to do so, reducing it from a mean split time of 5min/km in the first week to 5.28min/km ($p < 0.01$) for weeks 3-8.

The population considered in this study comprised distance runners who were presumably training for speed. Adding weight did not appear to support this goal, although it might have been interesting to observe the return to unweighted running for those that ran with weights. Furthermore, given the runners' maximal oxygen uptake, classified as "excellent" to "superior" (ACSM, 2009), it might follow that their upper body strength was of a level beyond being challenged by weights of 1.36kg each. Repeating this study using less fit or sedentary subjects may produce very different results.

Blessing, Wilson, Puckett and Ford (1987) investigated the use of hand-held weights during a programme of regular aerobic dance classes (3days/wk, 45min/day) within a population of previously sedentary women. Twenty-six women of student age (mean 20yrs) were divided into two groups. One group carried 0.45kg hand-held weights for

up to 20min of each of the 24 classes, the other group attended the same classes but without any weights.

During the eight weeks of exercise both groups experienced significant increases in $\dot{V}O_2\text{max}$; from $37.7 \pm 2.9 \text{ ml/kg/min}$ to $42.6 \pm 3.0 \text{ ml/kg/min}$ (14%) for the weighted group, and from $36.5 \pm 3.1 \text{ ml/kg/min}$ to $41.9 \pm 3.9 \text{ ml/kg/min}$ (13%) for the unweighted group ($p < 0.05$). These changes did not differ significantly between the two subject groups.

However the authors noted that throughout the exercise programme the mean reported HR was 170bpm for both groups, suggesting that the metabolic activity levels of the two groups were similar. Since the same upper and lower body choreography was used by all 26 women, those using weights may have made adjustments in tempo or movement to compensate for the additional load. No controls were in place to prevent this from happening, making direct comparison between the two groups questionable.

3.3. Rationale for and aims of the present study

Although several studies have considered the immediate physiological responses when weight is added to treadmill walking (Section 3.2), no data exists to describe the physiological changes that occur over time when hand-held weights are incorporated into a programme of regular brisk to aerobic walking, and whether these changes are significantly different to those associated with unweighted walking of a similar pace.

It is this absence in longitudinal studies which provides the rationale for the present study. Although there is strong evidence that weighted walking is more energetically demanding, it remains unconfirmed as to whether over time this low impact but potentially high-intensity workout achieves results safely but more quickly than walking alone.

3.3.1. *Rationale for hypotheses*

Carrying 0.91kg hand-held weights with an active arm swing increases the metabolic cost of brisk walking by approximately 2.0ml/kg/min (Eq. 3.1), making the exercise more demanding (Miller & Stamford, 1987; Morrow et al., 1992). At the same time, existing research suggests that if the added weight is less than 1.36kg, there is no increase in the rating of perceived exertion (Graves et al., 1987; Evans et al., 1994).

Combining these results, it is expected that walking with 0.91kg hand-held weights will provide for a more intensive exercise programme, and therefore one which produces greater improvements in cardiovascular fitness and body composition.

3.3.2. *Hypothesis 1*

Exercising with two 0.91kg (2lb) hand-held weights will have a significantly greater impact on aerobic fitness when compared with exercising without hand-held weights following a six-week programme of regular walking in previously sedentary women.

3.3.3. *Hypothesis 2*

Exercising with two 0.91kg (2lb) hand-held weights will have a significantly greater impact on body composition when compared with exercising without hand-held weights following a six-week programme of regular walking in previously sedentary women.

3.3.4. Rationale for the six-week exercise programme

The objectives of the exercise programme used in the present study were to:

1. overcome perceived barriers to exercise, maximise levels of adherence, and produce a positive and permanent lifestyle change
2. deliver a weekly exercise dose sufficient to protect against CHD and other chronic diseases over the long term
3. prescribe a duration, intensity and programme length sufficient to bring about improvements in cardiovascular fitness
4. incorporate hand-held weights in such a way as to further augment the exercise workload.

Careful consideration of the literature described and summarised in this and the preceding chapter lead to the following programme design:

- duration of six weeks
- 3×20min exercise bouts in Week 1, increasing to 3×30min by Week 3
- target exercise intensity of 60-75% of predicted $\dot{V}O_2\text{max}$, expected to deliver approximately 7.5MET-hours per week
- addition of hand-held weights on the third exercise bout using an active arm swing.

Chapter 4: RESEARCH DESIGN AND METHODS

4.1. Participants

Between June 2011 and March 2012, 14 healthy but sedentary women between the ages of 23 and 49yrs living in Hong Kong who were willing to accept random assignment into one of two exercise programmes were accepted into the study. One person withdrew after one week due to pressures of work; a second withdrew in her fifth week on medical grounds unrelated to the study. Data are therefore presented for the remaining 12 participants who were of mean age 37 ± 8 yrs, height 1.63 ± 0.07 m, weight 60.9 ± 9.8 kg, and BMI 22.9 ± 2.3 , six of Asian and six of Caucasian ethnicity.

Recruitment was conducted through various channels; the distribution of postcards and flyers, placement of magazine advertisements online and in print (Appendix A), listings on forum websites (www.GeoExpat.com, www.GeoBaby.com), and construction of a dedicated project website (www.sleepy8.com) linked to social media.

Ethical approval for the study was obtained from the Faculty of Applied Sciences Research Ethics Committee of the University of Chester, United Kingdom (Appendix B).

To assess suitability, participants completed a health screen and confirmed they had not undertaken regular exercise of any form in the preceding three months. A Participant Information Sheet was provided and written informed consent was obtained from each participant prior to entry into the study. All three documents were made available in both English and Cantonese (Appendix C).

4.2. Research design

The study was designed to assess the physiological changes induced by two unsupervised six-week exercise programmes of treadmill walking in previously healthy but sedentary female adults.

Participants were randomly assigned to one of two independent groups; hand-held weight group (HWG) or control group (CG). Participants in HWG carried commercially available 0.91kg (2lb) hand-held weights (Gold Medal Sports Wholesalers Co, Hong Kong) during their six-week exercise programme. Those in CG exercised without weights for the duration of the study.

The following five dependent variables representing cardiovascular fitness and body composition were compared between the two groups and over time using a repeated measures design:

1. predicted maximal oxygen uptake ($\dot{V}O_2\text{max}$)
2. 10min Treadmill Walk Test
3. body mass
4. waist circumference
5. sum of four skinfolds

When assessing changes in cardiovascular fitness, it was considered important to employ measurement procedures that correctly detected whole-body strength-endurance cross-training adaptations, noting that small weights were more likely to lead to changes in speed and endurance, heavier weights to increases in strength.

The present study used two tests to assess improvement in cardiovascular fitness. One, a submaximal treadmill-based exercise protocol limited to lower body muscle work (McGuigan, Alexander & Morris, 2009), was used to predict maximal oxygen uptake. The other, the 10min Distance Walk Test (Evans et al. 1994; Morrow et al., 1992), also conducted on a treadmill, incorporated hand-held weights to establish whether or not their use contributed to improvements in speed and efficiency when walking on a level surface.

4.3. Exercise programmes

Each participant reported to the study venue (Admiralty Fitness Studio, Pure International, Hong Kong) for an introductory session during which time was spent explaining in detail what was involved in their exercise programme and, if necessary, gaining familiarity with exercising on a motorised treadmill (Life Fitness, USA). Random assignment to a study group was completed through the drawing of a slip of paper from a cloth bag.

All participants were instructed to complete three walks on a treadmill at 0% incline per week, i.e. a total of 18 walks, with 48hrs between consecutive walks and between any walk and a key measures session. In Week 1 participants were instructed to walk for 20min, Week 2 for 25min, and Week 3-6 for 30min. Participants assigned to HWG introduced the hand-held weights after completion of the first two walks. The exercise programmes are set out schematically in Table 4.1.

Table 4.1: Summary of the two 6-week exercise programmes.

Group		Week 1	Week 2	Week 3	Week 4		Week 5	Week 6	
Hand-held weight group (HWG)	Baseline key measures	3 × 20min walking >5km/h ¹ Walk 1 & 2 with <u>no</u> HWs ²	3 × 25min walking >5km/h with HWs	3 × 30min walking >5km/h with HWs	3 × 30min walking >5km/h with HWs	Week 4 key measures	3 × 30min walking >5km/h with HWs	3 × 30min walking >5km/h with HWs	Week 6 key measures
Control group (CG)		3 × 20min walking >5km/h	3 × 25min walking >5km/h	3 × 30min walking >5km/h	3 × 30min walking >5km/h		3 × 30min walking >5km/h	3 × 30min walking >5km/h	

1: workload of 60-75% of predicted $\dot{V}O_2$ max, 2: HWs are hand-held weights

All walks were to be completed at greater than 5km/h and more specifically at a speed that elicited a submaximal workload of 60-75% of predicted $\dot{V}O_2$ max. This workload could only be identified and explained following the Baseline key measures (see Section 4.4.2.).

Participants were advised not to change dietary, exercise, or life-style habits for the duration of the study other than in the way prescribed above. Food diaries were completed on the day before each of the three key measures to assess whether participants had adhered to the recommendation not to change their eating habits (Appendix D). Once a participant was comfortable with all that was required of them during the study and still wished to continue, Baseline key measures were taken.

At the end of the introductory session, those participants randomly assigned to HWG were given two 0.91kg hand-held weights and coached on how to use them correctly. They were instructed to carry the weights with a 90° angle at the elbow and to swing their arms from the shoulder in counterbalance with hip movements as would normally occur. The weights were to be moved through an arc, reaching a height aligned with the shoulder on the forward swing and pulling back to just behind the torso on the backward swing (Miller & Stamford, 1987; Morrow et al., 1992) (Figure 4.1). Participants were also advised that straightening the arms briefly was permitted during the exercise programme to relax arm muscles and reduce any localised fatigue.

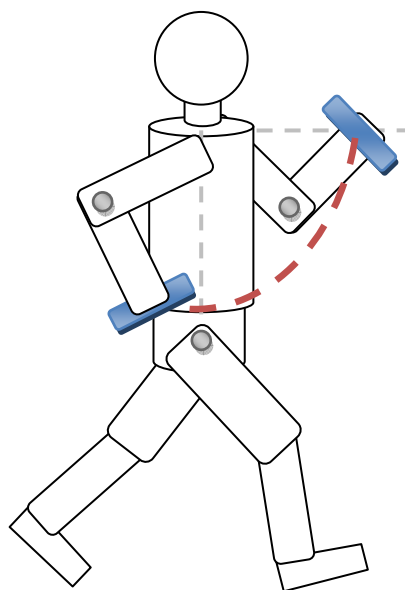


Figure 4.1: Schematic diagram showing the extent of the “active” arm swing during weighted walking.

4.4. Key measures

All key measures were taken by the lead researcher at the study venue. To prevent a time-of-day effect on physiological performance, Baseline, Week 4 and Week 6 key measures were conducted at the same time of day (± 2 hrs) for each participant (Reilly, 1990). Body composition measures were taken prior to any warm-up, exercise testing or treadmill familiarisation session.

4.4.1. Body composition

Standing height (H ; m) and body mass (m ; kg) were measured using balance beam scales with telescopic measuring rod (SECA, Germany). Participants were wearing loose-fitting exercise clothing, footwear removed. Body mass index (BMI), the most widely used index for assessing overweight and obesity, was calculated as body mass corrected by squared height (Eq. 4.1).

$$\text{BMI} = \frac{m}{H^2} (\text{kg/m}^2) \quad \text{Eq. 4.1}$$

Waist circumference (WC) was determined by placing a measuring tape laterally at the midpoint between the lowest part of the ribs and the highest part of the iliac crest. The participant was asked to gently exhale before a single measurement was taken, a procedure that was repeated three times and the average taken (ACSM, 2009).

Skinfold thickness was measured using a Harpenden skinfold calliper (John Bull British Indicators Ltd, England) at four sites (bicep, tricep, subscapular and suprailiac), each site measured three times in rotation and an average taken in accordance with the guidelines set out by ACSM (2009). The sum of the four averages was used as a measure of body fatness.

The participant was then asked to wear a heart rate monitor strap (Polar FT1, Finland) for the remainder of the session, during which time two fitness assessments were conducted. A standing resting HR was noted once the strap was in place.

4.4.2. Aerobic fitness

Direct measurement of $\dot{V}O_2\text{max}$ using a maximal exercise protocol was considered inappropriate in sedentary participants, five of whom presented with increased cardiovascular risk, indicated by waist circumference or BMI (Tables 4.2a,b). Instead the Chester Treadmill Walk Test (McGuigan et al., 2009), a sub-maximal test designed to predict aerobic capacity, was used.

Table 4.2a: Waist circumference (WC) and risk of metabolic complications associated with cardiovascular disease in Caucasian (Han, van Leer, Seidell & Lean, 1995) and Asian (Lee et al., 2002) adults.

action level	WC (cm)				risk of metabolic complications
	Caucasian adults		Asian adults		
	female	male	female	male	
normal	< 80	< 94	< 75	< 85	average
1	≥ 80	≥ 94	≥ 75	≥ 85	increased
2	≥ 88	≥ 102	n/a	n/a	substantially increase

Table 4.2b: BMI and risk of metabolic complications associated with cardiovascular disease in Caucasian (WHO, 2000) and Asian (Lee et al., 2002; WHO, 2004) adults.

classification	BMI (kg/m ²)		risk of metabolic complications
	Caucasian adults	Asian adults	
underweight	< 18.5	< 18.5	low*
normal	18.5 – 24.9	18.5 – 22.9	average
overweight	25.0 – 29.9	23.0 – 24.9	increased
obese	≥ 30.0	≥ 25.0	moderate to severe

***but associated with excess health risks owing to cigarette smoking, malnutrition or subclinical diseases**

Following a gentle loosening and limbering, each participant was asked to walk on a treadmill at 0% incline for a 3-5min warm-up during which time the speed was gradually increased to 6.2km/h by the participant; the speed that would be maintained for the duration of the protocol. The participant then completed a maximum of six 2min intervals at increasing gradient; 0% for the first 2min, increasing by 3% at the end of each interval to a maximum incline of 15%.

At the end of each 2min interval the participant's HR and RPE were recorded. Borg's scale (Borg, 1998) of perceived exertion was used and a Cantonese-translated version

of the scale made available (Leung, Leung & Chung, 2004). Instructions for its use were read to the participant and a copy made available to them for future use (Appendix E).

The test was stopped if/when the participant reached 80% of their age-predicted HR_{max} (Eq. 4.2), reported an RPE of 14 or above, or appeared unduly distressed (ACSM, 2009). Encouragement was given if a participant indicated at the start of an interval that it would be their last.

$$HR_{max} = 220 - \text{participant's age} \quad \text{Eq. 4.2}$$

HR data were plotted against $\dot{V}O_2$ (ml/kg/min) values determined using Eq. 4.3, a metabolic equation for the estimation of energy expenditure during walking (ACSM, 2009). The speed 6.2km/h was necessarily re-expressed in m/min (103.33m/min). Linear regression analysis was then used to estimate $\dot{V}O_{2max}$ (example presented in Appendix F).

$$\dot{V}O_2 = 3.5 + (0.1 \times 103.33) + (1.8 \times 103.33 \times \text{gradient}) \quad \text{Eq. 4.3}$$

Using the results of the Chester Treadmill Walk Test and the associated RPEs, participants were given guidance as to the level of exertion required to walk at 60-75% of their predicted $\dot{V}O_{2max}$ (example presented in Appendix F). This guidance was then put into practice during the second fitness assessment.

After a minimum of 3min active recovery, participants completed a 10min Distance Walk Test to establish how far they could walk during this time. The treadmill was held at 0% incline throughout and participants walked at a self-selected speed (>5km/h) which elicited a submaximal workload of 60-75% of predicted $\dot{V}O_{2max}$. HR was observed every 2min and the total distance walked was recorded (DW10; km). A normalised gait speed (NGS) was then computed by dividing average speed (m/s) by height (m):

$$NGS = \frac{6,000}{3,600} \times \frac{DW10}{H} \quad \text{Eq. 4.4}$$

At Baseline all participants completed the 10min Distance Walk Test without hand-held weights; at Week 4 and Week 6 those in HWG walked with their weights.

4.5. Exercise programme logs

For each of the 18 prescribed walks, participants recorded the following information:

- date of completion
- distance covered
- minimum and maximum speed
- RPE in the last 2min of exercise

This data was collated via a secure online database (www.sleepy8.com) to which each participant had a unique and confidential username and password. In turn this database gave participants access to a range of basic performance statistics; total distance covered during the six-week programme, average walking speed, and estimated total energy expenditure based on speed and body mass using tables published in Williams (2010), (Appendix G).

An interactive map reported their position along the Maclehole Trail, a 100km hiking path through the national parks of Hong Kong (Figure 4.2). The main objective in collating data in this way was to keep participants motivated to complete their exercise programme and continue walking beyond the prescribed six weeks.

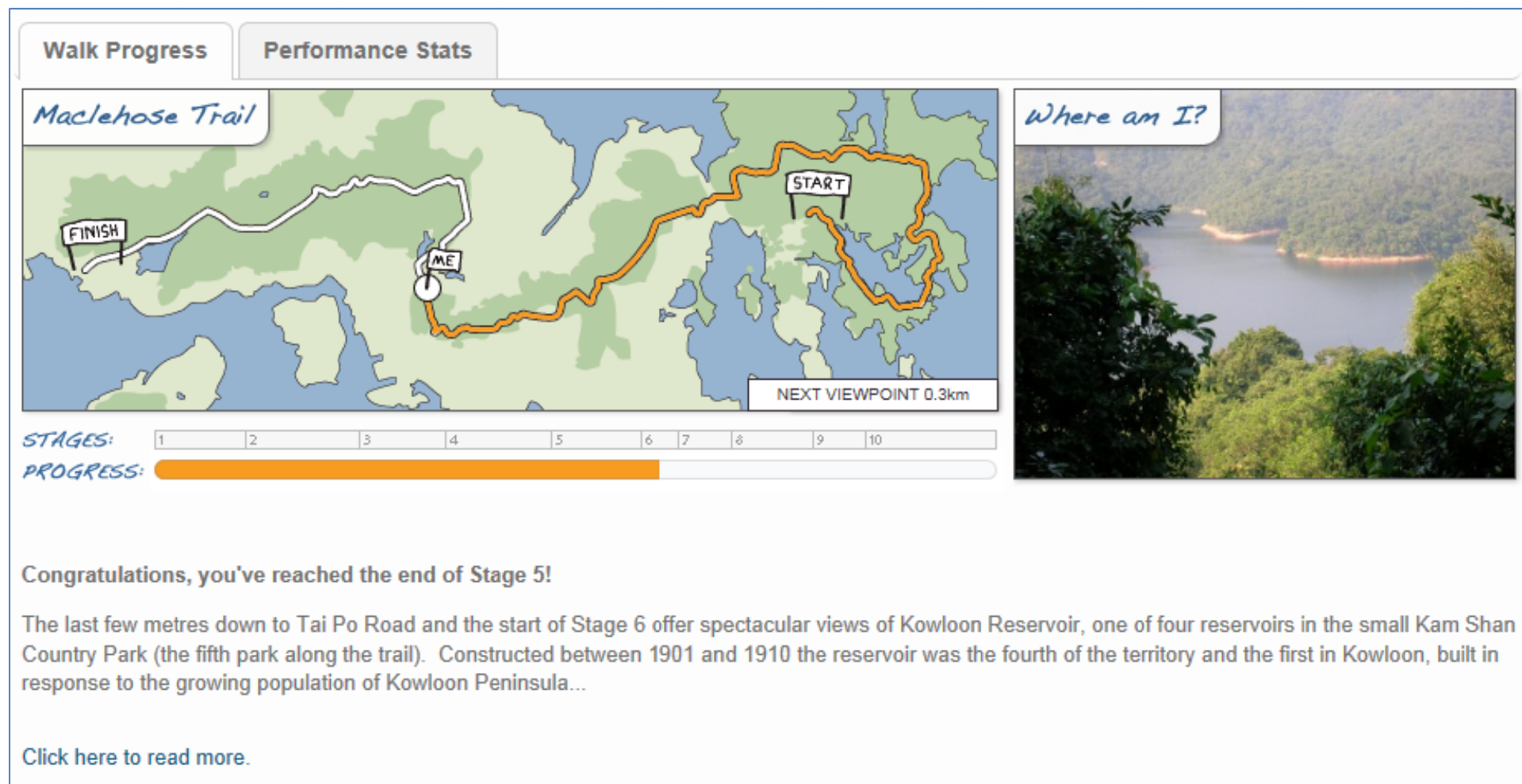


Figure 4.2: Interactive map of the Maclehoose Trail (Hong Kong) positioning a participant according to the cumulative distance covered as they progressed through their 6-week exercise programme.
(www.sleepy8.com)

4.6. Statistical analysis

Information provided in food diaries was analysed using the McCance & Widdowson database (Food Standards Agency, 2002) and supplemented with nutritional information obtained from food packaging and manufacturers' websites.

Descriptive statistics were used to examine data at baseline and, assuming parametric data, independent *t*-tests used to establish significant differences between the two groups.

Mixed model ANOVA tests were used to analyse differences in cardiovascular fitness, body composition and total energy intake across the two groups (HWG, CG) and at the three repeated measures (Baseline, Week 4, Week 6). Multiple independent *t*-tests between groups and paired *t*-tests within groups were used in post hoc analysis to establish the nature of any significant differences, applying a Bonferroni adjustment where appropriate to counter the increased risk of committing a Type-I error (Abdi, 2007).

For all statistical analysis, significance was registered at the 5% confidence level prior to Bonferroni adjustment. SPSS Statistics 17.0 for Windows® was used throughout.

Chapter 5: RESULTS

5.1. Participant characteristics

Random assignment of participants to the two exercise programmes resulted in two groups that did not differ significantly in any of the nine parametric characteristics measured at Baseline (Table 5.1). However, CG was on average taller and heavier than HWG with a greater tendency to be overweight and of a lower level of fitness. Four members of CG presented with increased cardiovascular risk, indicated by either waist circumference or BMI, versus only one in HWG.

Table 5.1: Mean (\pm SD) physical and physiological characteristics of the two study groups at Baseline; HWG and CG.

physical/physiological characteristic	HWG	CG	p value
N	6	6	
age (yrs)	37 \pm 7	38 \pm 9	NS
height (m)	1.60 \pm 0.06	1.65 \pm 0.08	NS
body mass (kg)	56.6 \pm 6.6	65.1 \pm 11.1	NS
BMI (kg/m ²)	22.1 \pm 1.6	23.8 \pm 2.6	NS
waist circumference (cm)	74.1 \pm 4.4	80.9 \pm 8.6	NS
sum of four skinfold sites (mm)	56 \pm 11	69 \pm 14	NS
predicted $\dot{V}O_2$ max (ml/kg/min)	37.0 \pm 4.7	33.4 \pm 6.4	NS
DW10 (km)	1.10 \pm 0.04	1.06 \pm 0.06	NS
normalised gait speed (m/s)	1.15 \pm 0.06	1.08 \pm 0.08	NS

NS denotes “not significant”

Food diaries were completed by 11 participants and no significant differences between or within groups were found (Table 5.2). In line with the physiological characteristics reported in Table 5.1, CG had a higher energy intake than HWG.

Table 5.2: Mean (\pm SD) total energy intake for HWG and CG on the day preceding each key measures session; Baseline, Week 4 and Week 6.

Group	N	Total energy intake (MJ, (kcal))		
		Baseline	Week 4	Week 6
HWG	6	7.0 \pm 1.4 (1,682 \pm 339)	6.8 \pm 2.3 (1,631 \pm 541)	7.1 \pm 2.3 (1,689 \pm 541)
CG	5	8.2 \pm 1.5 (1,955 \pm 358)	8.8 \pm 1.6 (2,110 \pm 383)	8.0 \pm 0.7 (1,902 \pm 163)

5.2. Adherence to and performance during the exercise programmes

The 12 women who took part in the study completed 100% of the prescribed walks. Illness or time spent travelling overseas for work meant that for five participants the total duration of the programme was extended beyond six weeks, while others reached completion a few days ahead of schedule. On average the time lapse between Baseline and the second key measure was 31days, and between Baseline and the third key measure was 48days. There was no significant variation between the groups.

During the 18 prescribed walks, HWG covered a mean total distance of 55.4 \pm 3.8km at a mean average walking speed of 6.7 \pm 0.5km/h (NGS 1.2 \pm 0.1m/s), rated with mean RPE of 13.2 \pm 1.5 on the Borg Scale. These performance statistics were not significantly different from those reported by CG; mean total distance of 55.0 \pm 4.1km, mean average walking speed of 6.7 \pm 0.5km/h (NGS 1.1 \pm 0.1m/s), mean RPE of 14.1 \pm 1.6.

The quadratic regression line shown in Figure 3.2 which estimates the relationship between walking speed and metabolic cost of walking (Ainsworth et al., 2011), is given by the equation

$$y = 0.2353x^2 - 1.4972x + 5.2, \text{ with } R^2 = 0.9922 \text{ (} p < 0.001 \text{)} \quad \text{Eq. 5.1}$$

Using Eq. 5.1, a walking speed of 6.7km/h on a level, firm surface demands a metabolic cost of 5.7METs, only slightly below the formal definition of vigorous exercise (6.0METs) and an intensity supported by mean RPEs which describe the exercise as

“somewhat hard” to “hard”. These results indicate that participants in both groups met the ACSM guidelines for exercise (ACSM, 1998) during their six-week walking programme.

Converting this workload in to MET-hours/wk (Eq. 2.2a,b), on average the participants were undertaking 8.6MET-hours/wk of physical activity as a direct result of the walking programme. This is well above the target of 7.5MET-hours/wk (Section 3.3.4.).

5.3. Changes in body composition over time

No significant differences between or within groups were found for body mass, waist circumference or sum of four skinfold sites (Table 5.3).

Table 5.3: Mean (\pm SD) body mass, waist circumference and sum of four skinfold sites for HWG and CG at Baseline, Week 4 and Week 6.

Key measure	HWG (N = 6)			CG (N = 6)		
	Baseline	Week 4	Week 6	Baseline	Week 4	Week 6
body mass (kg)	56.6 \pm 6.6	56.8 \pm 7.4	56.8 \pm 7.2	65.1 \pm 11.1	64.2 \pm 10.3	64.3 \pm 10.5
waist circumference (cm)	74.1 \pm 4.4	74.7 \pm 5.3	73.7 \pm 5.4	80.9 \pm 8.6	80.6 \pm 8.2	81.7 \pm 9.7
sum of four skinfold sites (mm)	56 \pm 11	57 \pm 12	54 \pm 13	69 \pm 14	67 \pm 13	65 \pm 15

5.4. Changes in aerobic fitness over time

5.4.1. Predicted $\dot{V}O_2\text{max}$

There were no significant differences in mean predicted $\dot{V}O_2\text{max}$ between the groups at Baseline, Week 4 or Week 6. However, the measure did increase in both groups; from $37.0 \pm 4.7 \text{ ml/kg/min}$ to $40.0 \pm 4.7 \text{ ml/kg/min}$ (8%) for HWG ($p=0.025$) and from $33.4 \pm 6.4 \text{ ml/kg/min}$ to $38.9 \pm 2.8 \text{ ml/kg/min}$ (16%) for CG ($p=0.050$) (Figure 5.1a). These increases did not register as significant since a Bonferroni adjustment had been made.

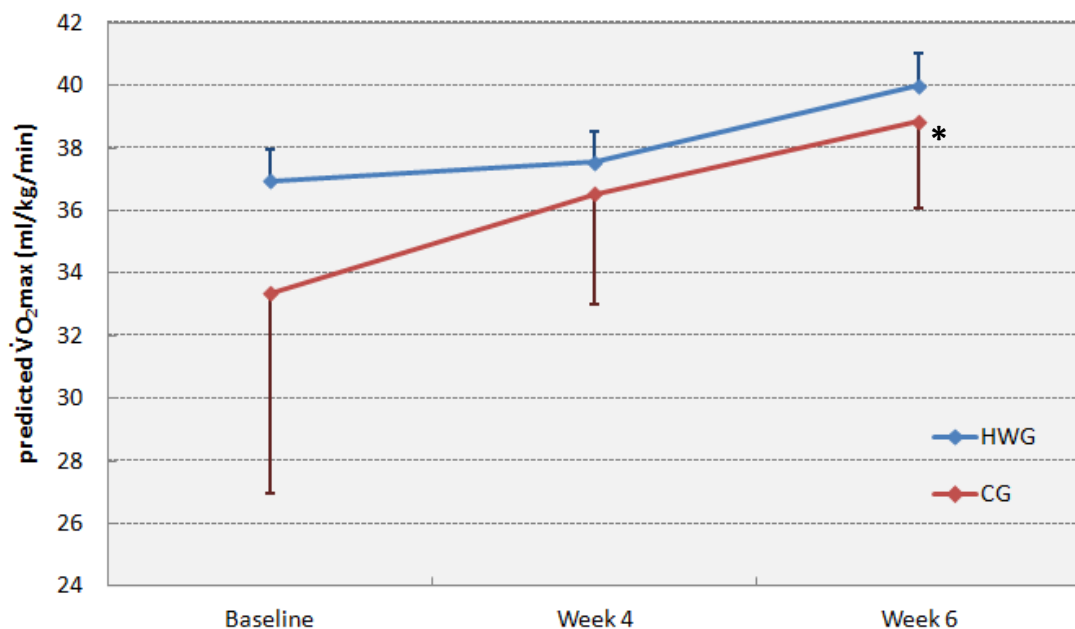


Figure 5.1a: Mean (\pm SD) predicted $\dot{V}O_2\text{max}$ for HWG (N=6) and CG (N=6) at Baseline, Week 4 and Week 6. *significantly different from value at Week 4 ($p<0.0167$). SD is shown in one direction only to ensure the graph remains legible.

What is clear from Figure 5.1a is the far greater variability in predicted $\dot{V}O_2\text{max}$ within CG than HWG, particularly at Baseline. This variability is driven by two participants with “very poor” Baseline predicted $\dot{V}O_2\text{max}$ (ACSM, 2009) who, over the course of the six-week programme achieved improvements in aerobic fitness of 35% and 50% respectively. Excluding these participants from this analysis reveals two groups which are more closely matched at Baseline, and whose mean predicted $\dot{V}O_2\text{max}$ increases at very similar rates (Figure 5.1b).

Considering the 12 women collectively, mean predicted $\dot{V}O_{2\max}$ increased significantly by 12% from $35.2 \pm 5.7 \text{ ml/kg/min}$ to $39.4 \pm 3.7 \text{ ml/kg/min}$ ($p=0.004$). If the two “outliers” are excluded from this calculation, the mean increase for the remaining ten participants is still significant but falls to 8% ($p=0.011$); $37.0 \pm 4.1 \text{ ml/kg/min}$ to $39.9 \pm 3.9 \text{ ml/kg/min}$.

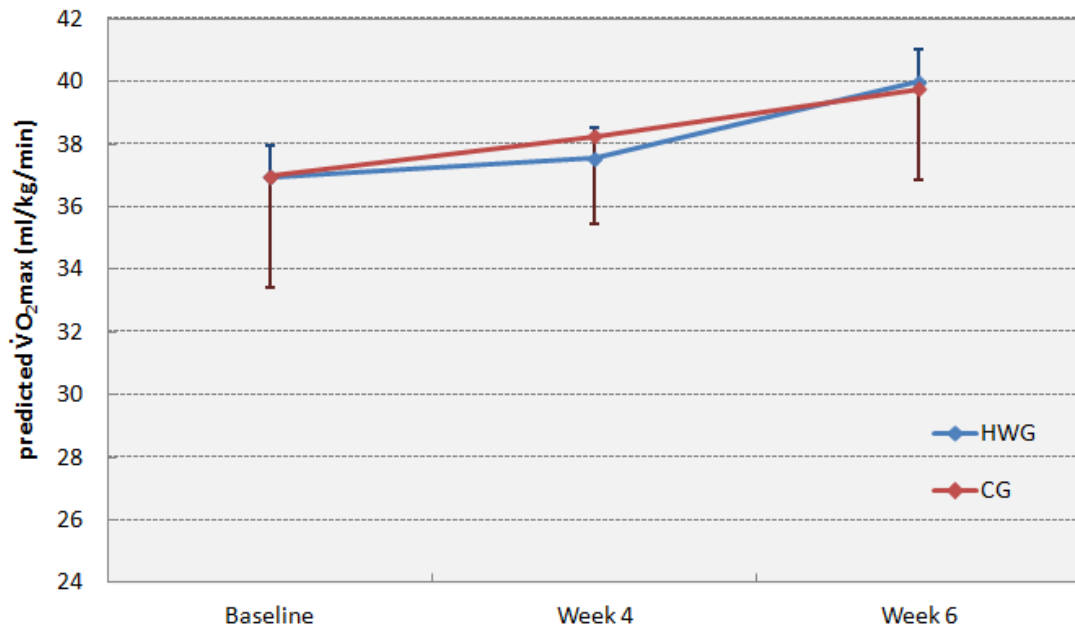


Figure 5.1b: Mean (\pm SD) predicted $\dot{V}O_{2\max}$ for HWG (N=6) and CG (N=4) at Baseline, Week 4 and Week 6 after removal of two participants with “very poor” Baseline data. SD is shown in one direction only to ensure the graph remains legible.

5.4.2. 10min Distance Walk Test

There were no significant differences in mean DW10 between the groups at Baseline, Week 4 or Week 6. Both groups achieved significant increases in DW10 between Baseline and Week 4, and between Baseline and Week 6 as shown in Table 5.4 ($p<0.0167$, Bonferroni adjustment). When DW10 was converted to NGS (m/s) the pattern of results remained unchanged (Table 5.4).

Table 5.4: Mean (\pm SD) DW10 and NGS recorded during the 10min Distance Walk Test for HWG and CG at Baseline, Week 4 and Week 6.

Group	N	DW10 (km); NGS (m/s)		
		Baseline	Week 4 ¹	Week 6 ¹
HWG	6	1.099 \pm 0.043 (1.15 \pm 0.06)	1.150 \pm 0.068* (1.20 \pm 0.09)*	1.166 \pm 0.072* (1.22 \pm 0.10)*
CG	6	1.064 \pm 0.059 (1.08 \pm 0.08)	1.152 \pm 0.075* (1.16 \pm 0.07)*	1.143 \pm 0.088* (1.16 \pm 0.10)*

1: HWG were carrying HWs

*significantly different from the value at Baseline ($p < 0.0167$, Bonferroni adjustment)

During the six weeks, participants in HWG increased DW10 by 0.067 ± 0.037 km ($6 \pm 3\%$), participants in CG by 0.078 ± 0.034 km ($7 \pm 3\%$); ($p < 0.0167$).

Participants were allowed to select and subsequently adjust the speed (>5 km/h) at which they walked, provided they exercised at a submaximal workload of 60-75% of predicted $\dot{V}O_{2\max}$. Since the equipment to monitor $\dot{V}O_2$ during the test was not available, as a proxy HR was recorded every 2min and expressed as absolute and as percentage of age-predicted HR_{\max} .

Tables 5.5a,b suggests that participants were exercising at an intensity very likely consistent with the target workload, and certainly at a level regarded as hard (ACSM, 1998).

Table 5.5a: Mean (\pm SD) minimum and maximum HR as percentage of age-predicted HR_{\max} recorded during the 10min Distance Walk Test for HWG and CG at Baseline, Week 4 and Week 6.

Group	N	min/max HR during 10min Distance Walk Test (% age-predicted HR_{\max})					
		Baseline		Week 4		Week 6	
HWG	6	76.0 \pm 6.8	81.2 \pm 10.2	83.1 \pm 7.2*	86.9 \pm 6.0	80.6 \pm 9.5	85.1 \pm 6.5
CG	5	78.8 \pm 5.0	81.0 \pm 5.0	81.7 \pm 7.3	85.2 \pm 7.6	79.2 \pm 9.7	83.9 \pm 10.0

*significantly different from the value at Baseline ($p < 0.0167$, Bonferroni adjustment)

Table 5.5b: Mean (\pm SD) average absolute HR recorded during the 10min Distance Walk Test for HWG and CG at Baseline, Week 4 and Week 6.

Group	N	average absolute HR during 10min Distance Walk Test (bpm)		
		Baseline	Week 4	Week 6
HWG	6	140 \pm 14	153 \pm 15*	147 \pm 16
CG	5	141 \pm 15	147 \pm 14	142 \pm 16

*significantly different from the value at Baseline ($p < 0.0167$, Bonferroni adjustment)

There were no significant differences in heart rates between groups at any of the key measures sessions. However, both the average absolute HR and the maximum HR as a percentage of age-predicted HR_{max} for HWG was higher at Week 4 and Week 6, i.e. when the hand-held weights were being carried.

Chapter 6: DISCUSSION

Based on the findings of the present study, exercising with two 0.91kg (2lb) hand-held weights does not have a significantly greater impact on aerobic fitness or body composition when compared with exercising without hand-held weights following a six-week programme of regular walking in previously sedentary women.

Nevertheless, a six-week programme comprising three brisk walks per week appears sufficient exercise to induce a meaningful increase in predicted $\dot{V}O_2\text{max}$, irrespective of whether hand-held weights are used. Mean predicted $\dot{V}O_2\text{max}$ of the 12 participants increased from $35.2 \pm 5.7 \text{ kg/ml/min}$ to $39.4 \pm 3.7 \text{ kg/ml/min}$ ($p=0.004$), a rise of 12% and comfortably inside the minimum range of $\dot{V}O_2\text{max}$ improvements (10-15%) expected with adherence to ACSM exercise guidelines (ACSM, 1998).

However, the six-week programme, weighted or unweighted, does not produce significant reductions in body mass, waist circumference or sum of four skinfold sites, at least not without simultaneous modifications to diet and lifestyle.

One possible explanation for the near parallel improvement in aerobic fitness of HWG and CG might come from the biomechanics of walking. Although several authors have reported increases in the energetic cost of walking when HWs are added (Auble et al., 1990, Maud et al., 1990, Miller & Stamford, 1987, Morrow et al., 1992), this was typically observed when changes in walking speed and stride frequency were prohibited; restrictions which independent of adding weight have been shown elsewhere to increase the cost of walking (Morgan & Martin, 1986). Furthermore, the arm swing employed in some cases (Auble et al., 1987) was a significant departure from a natural arm swing and quite possibly unable to provide any of the energy-reducing benefits observed by Pontzer et al. (2009) and Collins et al. (2009).

In the present study participants were free to choose both walking speed and stride frequency, provided exercise intensity remained within the target range.

It is possible that in allowing this to happen participants naturally sought the most economical gait, and one in which metabolic workload was simply transferred from the lower to the upper body, reducing the need for the leg muscles to resist the vertical ground reaction moment (Collins et al., 2009).

Furthermore, the spreading of the workload between a larger muscle mass has been linked to a sense of relative ease (Butt, Knox & Foley, 1995). This might explain the difference in RPE reported by the two groups; 13.2 ± 1.5 for HWG, 14.1 ± 1.6 for CG.

There is no evidence to suggest that the addition of hand-held weights caused undue stress or fatigue to the participants of HWG, or had a detrimental impact on their performance, which was not the case in Ewing et al. (1987) where running split time was compromised. HWG was able to walk at the same average speed (6.7 ± 0.5 km/h) and cover the same distance (55.4 ± 3.8 km vs 55.0 ± 4.1 km) as CG during the six weeks.

6.1. Limitations of the present study

There are several limitations in the design and implementation of the present study, and one or more of these limitations may have led to an incorrect rejection of the two hypotheses tested.

6.1.1. Participant sample size

An a priori statistical power calculation, conducted with power of 80% and based on existing and relevant research, indicated that a sample size of 48 would be needed to yield a statistically significant difference in the change in aerobic fitness of the two groups (Appendix H). This figure is four times larger than the sample size recruited here despite actively promoting the study for a period of five months.

However the power test was based on a series of assumptions, one of which was 70% adherence to the exercise programme, markedly lower than the 100% seen in the present study but consistent with that observed elsewhere (Murphy et al., 2002).

Repeating the power calculation using a more optimistic adherence level would produce a lower target sample size. Nonetheless, it is reasonable to assume that insufficient participant numbers will have impacted the statistical relevance of the results presented here.

6.1.2. Programme design and duration

A six-week exercise programme comprising three walks per week may have been too short and too infrequent for significant differences to become apparent.

Adherence to a prescribed exercise programme must be balanced with frequency and duration. While the present study can report 100% completion of the 18 programme walks, more meaningful results may have been derived from a longer exercise programme involving up to five walks per week (Duncan et al., 1991; Hardman & Hudson, 1994) despite the risk of higher dropout rates and lower adherence levels.

It may also have been more appropriate to introduce hand-held weights at a later stage in the exercise programme, and at a time when improvements in aerobic fitness might otherwise plateau if changes in intensity are not introduced. Indeed, allowing previously sedentary participants time to acclimatise to a programme of regular walking and to gradually increase their walking speed before adding weights may be a more natural progression and one which builds the exercise intensity more effectively.

Over a 24-week period, Duncan et al. (1991) observed a 5ml/kg/min (16%) increase in $\dot{V}O_2\text{max}$ as a result of regular aerobic walking at speeds rising incrementally to 8km/h, but an increase of only 3ml/kg/min (9%) if walking speeds were to reach only 6.4km/h. Rather than demanding higher speeds, hand-held weights might be added during a walking programme to provide further increases in exercise intensity and therefore a viable alternative to increasing speed when seeking further improvements in aerobic fitness.

6.1.3. *Weighted arm swing*

Despite time spent during the introductory sessions coaching participants in the correct use of the hand-held weights (Figure 4.1), the prescribed active arm swing was not maintained during the unsupervised six-week exercise programme. Observations made during the 10min Distance Walk Test at Week 4 and Week 6 confirmed that weights were not being moved through the full arc from shoulder height to just behind the torso, stopping short of both end points. In some cases, without further coaching the action approached normal arm swing.

Francis and Hoobler (1986), Owens et al. (1989), Maud et al. (1990), Morrow et al. (1992) reported no significant change in the metabolic cost of walking when normal arm swing was used to carry weights of 0.91-1.81kg. It is therefore realistic to expect that if all other aspects of the two exercise programmes were similar (frequency, duration, average speed and distance covered), very similar results would be seen in both groups.

6.1.4. *Participant characteristics*

Despite the differences not registering as significant, on average participants in HWG were fitter, healthier and less overweight than those in CG and improvements in aerobic fitness may have been smaller in HWG as a consequence of this imbalance.

Indeed it may be this fact alone that accounts for the 0.9pt difference in mean RPE during the 18 programme walks, especially given the two groups were walking at comparable speeds.

6.1.5. *Validity and reliability of the Chester Treadmill Walk Test*

Given the sedentary lifestyle and health status of the study participants at the start of their six-week programme, it was appropriate to use a submaximal exercise protocol to estimate $\dot{V}O_2\text{max}$.

The present study took place in Hong Kong without access to dedicated sports science facilities and specialist measuring equipment, hence limited options were available. The Chester Treadmill Walk Test requires access to relatively basic equipment; motorised treadmill, heart rate monitor, RPE definition sheet and the resources to perform linear regression analysis (Appendix F).

While initial research into the validity and reliability of this test (McGuigan et al., 2009) concluded the test's accuracy was questionable based on consistent overestimation of actual $\dot{V}O_2\text{max}$, the same study advocated the test as a reliable tool for aerobic fitness measurement given close agreement between repeated measures.

These conclusions supported the use of the test in the present study since improvements in, rather than absolute levels of, aerobic fitness were being assessed. However, the work of McGuigan et al. (2009) was conducted on a sample size of only seven, calling into question the veracity of the results.

6.2. Comparison with previous findings

6.2.1. The impact of hand-held weights

The results of the present study are in agreement with Ewing et al. (1987) who observed no difference in the change in $\dot{V}O_2\text{max}$ between two groups of experienced male runners, one group running with progressively heavier hand-held weights (0.45-1.36kg), the other without.

However, the two groups experienced statistically insignificant increases in $\dot{V}O_2\text{max}$, most likely due to the existing fitness level of the athletes considered. A more valid comparison would be a similar study conducted using less fit subjects, more likely to see improvements in aerobic fitness during eight weeks of distance running.

The results presented here are also in agreement with Blessing et al. (1987) whose younger but otherwise comparable population experienced similar improvements in

$\dot{V}O_2\text{max}$ during a programme of regular aerobic dance irrespective of whether hand-held weights (0.45kg) were added during the classes. However, the authors observed no difference between the mean HR of the two groups when exercising and suspected that the additional metabolic cost of lifting the weight had been countered by a reduction in tempo or range of movement. This would support the lack of difference between the groups' results.

In the present study, HR recorded during the 10min Distance Walk Test was higher for HWG at Week 4 and Week 6 when weights were carried, although not significantly so, suggesting that the weights did have a marginal impact on the intensity of the exercise. However, this difference in HR cannot be assumed to have been present during the 18 programme walks when heart rate was not monitored, leaving it difficult to explain the uniformity of results in the same way as Blessing et al. (1987).

6.2.2. Aerobic fitness

Although the two hypotheses put forward in this study have been rejected, the data obtained in relation to aerobic fitness supports the findings of previous studies examining the impact of regular walking on previously sedentary adults.

The increase in $\dot{V}O_2\text{max}$ observed across HWG and CG collectively is consistent with that of the aerobic walkers of Duncan et al. (1991), both in terms of magnitude (4.3ml/kg/min present study vs 5ml/kg/min) and percentage (12% present study vs 16%). Despite a difference in mean walking pace (6.7km/h present study vs 7.35km/h), participants in both studies were exercising at levels $\geq 80\%HR_{\text{max}}$.

The results in the present study were achieved in six weeks as opposed to 24 weeks in the case of Duncan et al. (1991). Without the availability of intermediary data it is impossible to draw more detailed comparisons between the two studies as to the progression in aerobic fitness.

The collective increase in $\dot{V}O_2\text{max}$ observed here is also consistent with that of the brisk walkers of Murphy et al. (2002) who observed a mean 3.8ml/kg/min or 14.1% rise during the first of two six-week exercise programmes in which they were instructed to work at an intensity 70-80% of their predicted HR_{max} .

6.3. Health benefits brought to the participants

Given the similarities between participants in the present study and the subjects of Duncan et al. (1991), Hardman and Hudson (1994) and Murphy et al. (2002), it is reasonable to expect participants' HDL cholesterol concentrations to have risen during the six weeks by amounts comparable to those previously observed by these authors; 0.05-0.12mmol/L or 4-9%. Particularly in relation to those participants who presented with increased risk of cardiovascular disease at Baseline, a population for which data exists to support the benefits of increased HDL cholesterol concentrations (Manninen et al., 1988; Devendra et al., 2010), such positive changes could lead to a less atherogenic lipid profile.

Both HWG and CG achieved a mean average walking speed of $6.7 \pm 0.5 \text{ km/h}$ during the six-week exercise programmes, a speed that is of borderline vigorous exercise intensity at 5.7METs. Walking at this speed for 30min three times per week is equivalent to a workload of 8.6MET-hours/wk, and if maintained over the longer term would be sufficient to lower the risk of CHD by between 30% (Manson et al., 1999) and 51% (Lee et al., 2001), and the risk of type-2 diabetes by 31% (Hu et al., 1999).

At Baseline the metabolic equivalent maximal energy consumption (M_{max}) for two of the 12 participants was below the 9.0METs (31.5ml/kg/min) asymptotic value proposed by Blair et al. (1989) as the level at which age-adjusted, all-cause mortality rates approached their lowest rate for women, and above which additional health benefits were not necessarily conferred (Figure 2.1). By then end of the six-week

programme, all participants had a M_{\max} value which exceeded this threshold by at least 0.5METs.

Furthermore, after six weeks of regular walking ten of the 12 participants were regarded as having “high cardiorespiratory fitness” based on the classification described by Blair et al. (1996) and the population data presented by ACSM (2009). For these ten participants the observations of Blair et al. (1989) and Blair et al. (1996) suggest that irrespective of the presence of secondary mortality predictors, the relative risk of death from CVD and all causes is notably reduced when compared with their unfit, high-risk peers (Figure 2.2).

Of course the health benefits highlighted above only exist if the exercise programme is incorporated into the participants’ lifestyle on a permanent basis.

6.4. Areas of further research

A first step would be to address the limitations of the present study and the works of others on the use of hand-held weights during medium term endurance exercise programmes, and their impact on aerobic fitness.

Given much but not all of existing research into weighted walking is based on sedentary populations, it might be more appropriate to introduce weights further down the line in a longer duration exercise programme. This would allow for all subjects to become comfortable undertaking regular brisk walks, to experience some improvement in aerobic fitness and to reach a point where an increase in exercise intensity might be warranted if further improvements are to occur.

At this point one of several approaches might be taken which, if considered within the same study, would allow for more than one comparison to be made:

1. subjects continue walking with the same frequency but increase walking speed

2. subjects continue walking with the same frequency but introduce hand-held weights using an active arm swing
3. subjects continue exercising with the same frequency but replacing one or more walks with a jog or run
4. subjects continue walking with the same frequency and exercise intensity (control).

A study of this form would be a significant undertaking but one which could position weighted-walking as a valid alternative to faster walking or running, with a measure of the relative impact it might have. All exercise options can be undertaken on a treadmill and progress measured using the same testing protocol. Duncan et al. (1991) would provide a valid comparison for the results.

Certainly given this is the first study to have considered the effects of hand-held weights on physiological adaptations to walking exercise, other studies in this area are needed.

6.5. Conclusion

The main finding of the present study is that the addition of 0.91kg hand-held weights to a six-week regular walking programme when undertaken by previously sedentary women, did not have a significantly greater impact on aerobic fitness or body composition than unweighted walking.

Both forms of exercise were shown to induce meaningful improvements in aerobic fitness; 3.0ml/kg/min (8%) for weighted walking, 5.5ml/kg/min (16%) for unweighted walking. It is likely that the small sample size prevented these results from registering as statistically significant.

There is no evidence to support the introduction of hand-held weights at the beginning of a walking programme for previously sedentary women if the objective is one of accelerating the improvement in aerobic fitness or body composition. Conversely, no negative consequences of doing so were observed here.

REFERENCES

- Abdi, H. (2007). Bonferroni and Sidak corrections for multiple comparisons. In N. J. Salkind (Editor), *Encyclopaedia of measurement and statistics*. Thousand Oaks (CA): Sage
- Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R., Tudor-Locke, C., et al. (2011). 2011 Compendium of physical activities: a second update of codes and MET values. *Medicine and Science in Sports and Exercise*, 43(8), 1575-1581.
- American College of Sports Medicine (1998). ACSM Position Stand: The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Medicine and Science in Sports and Exercise*, 30(6), 975-991.
- American College of Sports Medicine (2009). *ACSM's Guidelines for Exercise Testing and Prescription*. (8th edition). Philadelphia (PA): Lippincott Williams & Wilkins.
- Auble, T. E., Schwartz, L., & Robertson, R. (1987). Aerobic requirements for moving handweights through various ranges of motion while walking. *The Physician and Sportsmedicine*, 15(6), 133-140.
- Auble, T. E., & Schwartz, L. (1991). Physiological effects of exercising with handweights. *Sports Medicine*, 11(4), 244-256.
- Berlin, J. A., & Colditz, G. A. (1990). A meta-analysis of physical activity in the prevention of coronary heart disease. *American Journal of Epidemiology*, 132(4), 612-628.
- Blair, S. N., Kohl, H. W., Paffenbarger, R. S., Clark, D. G., Cooper, K. H., & Gibbons, L. W. (1989). Physical fitness and all-cause mortality: a prospective study of healthy men and women. *Journal of the American Medical Association*, 262(17), 2395-2401.
- Blair, S. N., Kampert, J. B., Kohl, H. W., Barlow, C. E., Macera, C. A., Paffenbarger, R. S., et al. (1996). Influences of cardiovascular fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *Journal of the American Medical Association*, 276(3), 205-210.
- Blair, S. N., & Morris, J. N. (2009). Healthy hearts – and the universal benefits of being physically active: physical activity and health. *Annals of Epidemiology*, 19(4), 253-256.
- Blessing, D. L., Wilson, G. D., Puckett, J. R., & Ford, H. T. (1987). The physiologic effects of eight weeks of aerobic dance with and without hand-held weights. *American Journal of Sports Medicine*, 15(5), 508-510.
- Butts, N. K., Knox, K. M., & Foley, T. S. (1995). Energy costs of walking on a dual-action treadmill in men and women. *Medicine and Science in Sports and Exercise*, 27(1), 121-125.
- Borg, G. (1962). *Physical performance and perceived exertion*. Published Doctoral Thesis, Sweden: Gleerups.
- Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, 14(5), 377-381.
- Borg G. (1998). *Borg's perceived exertion and pain scales*. Champaign (IL): Human Kinetics.
- Collins, S. H., Adamczyk, P. G., & Kuo, A. D. (2009). Dynamic arm swinging in human walking. *Proceedings of the Royal Society of Biological Sciences*, 276(1673), 3679-3688.

Impact of hand-held weights on treadmill walking in previously sedentary women

- Devendra, G. P., Whitney, E. J., & Krasuski, R. A. (2010). Impact of increases in high-density lipoprotein cholesterol on cardiovascular outcomes during the Armed Forces Regression Study. *Journal of Cardiovascular Pharmacology and Therapeutics*, 15(4), 380-383.
- Duncan, J. J., Gordon, N. F., & Scott, C. B. (1991). Women walking for health and fitness - how much is enough? *Journal of the American Medical Association*, 266(23), 3295-3299.
- Evans, B. W., Potteiger, J. A., Bray, M. C., & Tuttle, J. L. (1994). Metabolic and hemodynamic responses to walking with hand weights in older individuals. *Medicine and Science in Sports and Exercise*, 26(8), 1047-1052.
- Ewing, A., Vandeputte, H., & Kennon, F. (1987). Effects of exercise with light hand weights on strength. *The Journal of Orthopaedic and Sports Physical Therapy*, 8(11), 533-536.
- Fisher, J. P., & White, M. J. (2004). Muscle afferent contributions to the cardiovascular response to isometric exercise. *Journal of Experimental Physiology*, 89(6), 639-646.
- Food Standards Agency (2002). *McCance and Widdowson's the Composition of Foods*. (6th summary edition). Cambridge: Royal Society of Chemistry
- Francis, K., & Hoobler, T. (1986). Changes in oxygen consumption associated with treadmill walking and running with light hand-carried weights. *Ergonomics*, 29(8), 999-1004.
- Graves, J. E., Pollock, M. L., Montain, S. J., Jackson, A. S., & O'Keefe, J. M. (1987). The effect of hand-held weights on the physiological responses to walking exercise. *Medicine and Science in Sports and Exercise*, 19(3), 260-265.
- Graves, J. E., Martin, A. D., Miltenberger, L. A., & Pollock, M. L. (1988). Physiological responses to walking with hand weights, wrist weights, and ankle weights. *Medicine and Science in Sports and Exercise*, 20(3), 265-271.
- Han, T. S., van Leer, E. M., Seidell, J. C., & Lean, M. E. J. (1995). Waist circumference action levels in the identification of cardiovascular risk factors: prevalence study in a random sample. *British Medical Journal*, 311(7017), 1401-1405.
- Hardman, A. E., & Hudson, A. (1994). Brisk walking and serum lipid and lipoprotein variables in previously sedentary women – effect of 12 weeks of regular brisk walking followed by 12 weeks of detraining. *British Journal of Sports Medicine*, 28(4), 261-266.
- Haskell, W. L., Lee, I. M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., et al. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*, 116(9), 1081-1093.
- Heady, J. A., Morris, J. N., Kagan, A., & Raffle, P. A. B. (1961). Coronary heart disease in London busmen: a progressive report with particular reference to physique. *British Journal of Preventative and Social Medicine*, 15(4), 143-153.
- Herr, H., & Popovic, M. (2008). Angular momentum in human walking. *The Journal of Experimental Biology*, 211(4), 467-481.
- Hu, F. B., Sigal, R. J., Rich-Edwards, J. W., Colditz, G. A., Solomon, C. G., Willett, W. C., et al. (1999). Walking compared with vigorous physical activity and risk of type 2 diabetes in women. *Journal of the American Medical Association*, 282(15), 1433-1439.

Impact of hand-held weights on treadmill walking in previously sedentary women

- Hu, F. B., Li, T. Y., Colditz, G. A., Willett, W. C., & Manson, J. E. (2003). Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *Journal of the American Medical Association*, 289(14), 1785-1791.
- Kagan, A. (1960). Atherosclerosis of the coronary arteries – epidemiological considerations. *Proceedings of the Royal Society of Medicine*, 53(1), 18-22.
- Lee, I. M., Rexrode, K. M., Cook, N. R., Manson, J. E., & Buring, J. E. (2001). Physical activity and coronary heart disease in women: is “no pain, no gain” passé? *Journal of the American Medical Association*, 285(11), 1447-1454.
- Lee, Z. S. K., Critchley, J. A. J. H., Ko, G. T. C., Anderson, P. J., Thomas, G. N., Young, R. P., Chan, T. Y. K., Cockram, C. S., et al. (2002). Obesity and cardiovascular risk factors in Hong Kong Chinese. *Obesity Reviews*, 3(3), 173-182.
- Lejeune, T. M., Willems, P. A., & Heglund, N. C. (1998). Mechanics and energetics of human locomotion on sand. *The Journal of Experimental Biology*, 201(13), 2071-2080.
- Leung, R. W., Leung, M. L., & Chung, P. K. (2004). Validity and reliability of a Cantonese-translated rating of perceived exertion scale among Hong Kong adults. *Perceptual and Motor Skills*, 98(2), 725-735.
- Manninen, V., Elo, M. O., Frick, M. H., Haapa, K., Heinonen, O. P., Heinsalmi, P., et al. (1988). Lipid alterations and decline in the incidence of coronary heart disease in the Helsinki Heart Study. *Journal of the American Medical Association*, 260(5), 641-651.
- Manson, J. E., Hu, F. B., Rich-Edwards, J. W., Colditz, G. A., Stampfer, M. J., Willett, W. C., et al. (1999). A prospective study of walking as compared with vigorous exercise in the prevention of coronary heart disease in women. *The New England Journal of Medicine*, 341(9), 650-658.
- Manson, J. E., Greenland, P., LaCroix, A. Z., Stefanick, M. L., Mouton, C. P., Oberman, A., et al. (2002). Walking compared with vigorous exercise for the prevention of cardiovascular events in women. *The New England Journal of Medicine*, 347(10), 716-725.
- Maud, P. J., Stokes, G. D., & Stokes, L. R. (1990). Stride frequency, perceived exertion, and oxygen cost response to walking with variations in arm swing and hand-held weight. *Journal of Cardiopulmonary Rehabilitation*, 10(8), 294-299.
- McGuigan, R. A., Alexander, R., & Morris, M. (2009). Reliability and validity of the Chester treadmill walk test for the prediction of aerobic capacity. Unpublished masters dissertation, University of Chester. (Available at: <http://hdl.handle.net/10034/114806>)
- Miller, J. F., & Stamford, B. A. (1987). Intensity and energy cost of weighted walking vs. running for men and women. *Journal of Applied Physiology*, 62(4), 1497-1501.
- Morgan, D. W., & Martin, P. E. (1986). Effects of stride length alteration on racewalking economy. *Canadian Journal of Applied Sports Sciences*, 11(4), 211-217.
- Morris, J. N., Heady, J. A., Raffle, P. A. B., Roberts, C. G., & Parks, J. W. (1953). Coronary heart-disease and physical activity of work. *The Lancet*, 262(6795), 1053-1057.
- Morris, J. N., & Crawford, M. D. (1958). Coronary heart disease and physical activity at work: evidence of a national necropsy survey. *British Medical Journal*, 2(5111), 1485-1496.
- Morrow, S. K., Bishop, P. A., & Teare Ketter, C. A. (1992). Energy cost of self-paced walking with handheld weights. *Research Quarterly for Exercise and Sport*, 63(4), 435-437.

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- Murphy, M. H., Nevill, A. M., Neville, C., Biddle, S., & Hardman, A. E. (2002). Accumulating brisk walking for fitness, cardiovascular risk, and psychological health. *Medicine and Science in Sports and Exercise*, 34(9), 1468-1474.
- Murphy, M. H., Nevill, A. M., Murtagh, E. M., & Holder, R. L. (2007). The effect of walking on fitness, fatness and resting blood pressure: A meta-analysis of randomised, controlled trials. *Preventive Medicine*, 44(5), 377-385.
- Ortega, J. D., Fehلمان, L. A., & Farley, C. T. (2008). Effects of aging and arm swing on the metabolic cost of stability in human walking. *Journal of Biomechanics*, 41(16), 3303-3308.
- Owens, S. G., Al-Ahmed, A., & Moffatt, R. J. (1989). Physiological effects of walking and running with hand-held weights. *The Journal of Sports Medicine and Physical Fitness*, 29(4), 384-387.
- Petrofsky, J. S., Phillips, C. A., Sawka, M. N., Hanpeter, D., Lind, A. R., & Stafford, D. (1981). Muscle fiber recruitment and blood pressure response to isometric exercise. *Journal of Applied Physiology*, 50(1), 32-37.
- Pontzer, H., Holloway, J. H., Raichlen, D. A., & Lieberman, D. E. (2009). Control and function of arm swing in human walking and running. *The Journal of Experimental Biology*, 212(4), 523-534.
- Reilly, T. (1990). Human circadian rhythms and exercise. *Critical Reviews in Biomedical Engineering*, 18(3), 165-180.
- Sawka, M. N. (1986). Physiology of upper body exercise. *Exercise and Sport Sciences Reviews*, 14(1), 175-211.
- Siegel, P. Z., Brackbill, R. M., & Heath, G. W. (1995). The epidemiology of walking: implications for promoting activity among sedentary groups. *American Journal of Public Health*, 85(5), 706-710.
- Tan, K. H., Cotterrell, D., Sykes, K., Sissons, G. R. J., de Cossart, L., & Edwards, P. R. (2000). Exercise training for claudicants: changes in blood flow, cardiorespiratory status, metabolic functions, blood rheology and lipid profile. *European Journal of Vascular and Endovascular Surgery*, 20(1), 72-78.
- Tongen, A., & Wunderlich, R. E. (2010). Biomechanics of running and walking. *Mathematics and Sports, Mathematics Awareness Month*. (Available at: <http://www.mathaware.org/mam/2010/essays/>)
- Umberger, B. R. (2008). Effects of suppressing arm swing on kinematics, kinetics, and energetics of human walking. *Journal of Biomechanics*, 41(11), 2575-2580.
- William, M. H. (2010). *Nutrition for health, fitness and sport*. (9th edition). New York (NY): McGraw-Hill.
- World Health Organization (2000). Obesity: preventing and managing the global epidemic. *WHO Technical Report Series*, 894(3), i-xii, 1-253.
- World Health Organization (2004). Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *The Lancet*, 363(9403), 157-163.

APPENDICES

A. Participant recruitment



Sleepy8 Needs You!

Take part in a research study and get fitter for free!

Walk with or without handweights 3 times a week for 6 weeks. Start at a time that works for you

- state-of-the-art fitness equipment
- progress checks online & one-to-one
- a fitness goodie bag when you're done
- kick-start to a fitter and healthier you!

contact Deborah on 6681 1056 or email 0916333@chester.ac.uk

 www.sleepy8.com  @Sleepy8fitness  Sleepy8

This study will take place in Hong Kong and has ethical approval from the Faculty of Applied Sciences Research Ethics Committee, University of Chester, UK.

Figure A.1: Advert placed in HK Magazine on 9 December 2011 and 30 December 2011.



Participants wanted for academic research into the impact of walking on fitness

Walk with or without handweights 3 times a week for 6 weeks, starting at a time that works for you

- state-of-the-art fitness equipment
- progress checks online & one-to-one
- a fitness goodie bag when you're done
- kick-start to a fitter and healthier you!

 www.sleepy8.com  @Sleepy8fitness  Sleepy8 *Sleepy8*

Contact Deborah on 6681 1056 or email 0916333@chester.ac.uk

This study will take place in Hong Kong and has ethical approval from the Faculty of Applied Sciences Research Ethics Committee, University of Chester, UK.

Figure A.2: Advert placed in HK Magazine on 3 February 2012, The List on 16-29 February 2012, and distributed as a flyer throughout February and March 2012 in various locations around Central, Hong Kong.

Sponsored [Create an Ad](#)

Sleepy8



WANTED: Volunteers to take part in a fitness research study. Not currently exercising on a regular basis? Join NOW!
www.sleepy8.com

 Like 92 people like this.

Figure A.3: Facebook recruitment campaign, run from November 2011 to February 2012, inclusive.

B. Ethical approval

The following two pages comprise the approval correspondence from the Faculty of Applied Sciences Research Ethics Committee, University of Chester, dated 18 March 2011.

[*To be replaced by PDF 01 Appendix B - Ethical Approval.*]

[*To be replaced by PDF 01 Appendix B - Ethical Approval.*]

C. Participant Information Sheet, Pre-study Questionnaire and Consent Form

The following nine pages contain the three documents listed, made available to potential participants in both English and Cantonese.

[*To be replaced by PDF 02 Appendix C - Part_info_sheet_eng.*]

[*To be replaced by PDF 02 Appendix C - Part_info_sheet_eng.*]

[*To be replaced by PDF 03 Appendix C - Part_info_sheet_can.*]

[*To be replaced by PDF 03 Appendix C - Part_info_sheet_can.*]

[*To be replaced by PDF 03 Appendix C - Part_info_sheet_can.*]

[*To be replaced by PDF 04 Appendix C - Pre-study_quest_eng.*]

[*To be replaced by PDF 05 Appendix C - Pre-study_quest_can.*]

[*To be replaced by PDF 06 Appendix C - Consent_form_eng.*]

[*To be replaced by PDF 07 Appendix C - Consent_form_can.*]

D. 24-hour food diary

The following two pages show a sample 24-hour food diary similar to that completed by each participant on the day prior to a key measures session:

Please complete a Food Diary for the 24hrs prior to each of your Key Measures.

Your Food Diary should be submitted when you attend each key measures session with Deborah. Please do not hesitate to get in touch with her if you have any questions regarding completion of the diary.

To assist in this process, here is an example of a completed diary indicating the sort of information that is required.

Date: 26 April 2012

Key measure: Baseline / Week 4 / Week 6

Breakfast		
Time: 07:30	Location: <i>home</i>	
¹ Food description	portion size/ weight/quantity	² nutritional information from packaging
<i>glass of orange juice</i>	<i>240ml</i>	<i><u>Prebiotic Muesli:</u> (per 100g) 10.6g protein, 57.0g carbohydrate, 9.4g fat</i>
<i>prebiotic muesli</i>	<i>90g</i>	
<i>low fat milk</i>	<i>110ml</i>	
<i>kiwi fruit</i>	<i>1 fruit</i>	
<i>black tea with low fat milk</i>	<i>1 mug</i>	
Mid-morning snack		
Time: 10:30	Location: <i>at my desk at work</i>	
¹ Food description	portion size/ weight/quantity	² nutritional information from packaging
<i>peppermint tea</i>	<i>1 mug</i>	
<i>milk chocolate</i>	<i>45g bar</i>	
Lunch		
Time: 13:00	Location: <i>sitting outside</i>	
¹ Food description	portion size/ weight/quantity	² nutritional information from packaging
<i>diet coke</i>	<i>330ml</i>	<i><u>M&S sandwich:</u> (per 100g) 12.5g protein, 24.5g carbohydrate, 4.9g fat</i>
<i>M&S turkey & cranberry sandwich</i>	<i>one package weighing 235g</i>	
<i>yoghurt</i>	<i>150g</i>	<i><u>Yoghurt:</u> (per 100g) 3.1g protein, 20.5g carbohydrate, 9.6g fat</i>

Mid-afternoon snack		
Time: 16:30	Location: at my desk at work	
¹ Food description	portion size/ weight/quantity	² nutritional information from packaging
café latte	tall size	bought at Starbucks
Dinner		
Time: 19:30	Location: home	
¹ Food description	portion size/ weight/quantity	² nutritional information from packaging
roasted chicken (with skin)	¼ of a chicken	
brown rice (boiled with salt)	150g	
roasted pumpkin and green peppers with garlic & olive oil	75g pumpkin & half a green pepper	
white wine	2 x 125ml glasses	
peppermint tea	1 mug	
Supper		
Time:	Location:	
¹ Food description	portion size/ weight/quantity	² nutritional information from packaging
not applicable		

Notes:

1. Where possible, indicate how the food has been prepared, e.g. roasted in olive oil, boiled in salted water, etc.
2. Please provide information from nutrition labels and food packaging if this is easier to do. The pieces of information to note are the amounts of total carbohydrates, fats and protein that are contained in the product, which are typically given per 100g, and the actual weight of the product consumed.

E. Rating of Perceive Exertion (RPE) Sheet

The following information was provided to all participants on a laminated sheet for ease of use in the gym while completing their programme walks:

RPE		Description
6	No exertion at all	沒有疲勞的感覺
7	Extremely light	極之輕鬆
8	-	-
9	Very light	非常輕鬆
10	-	-
11	Light	輕鬆
12	-	-
13	Somewhat hard	有點兒辛苦
14	-	-
15	Hard (heavy)	辛苦
16	-	-
17	Very hard	非常辛苦
18	-	-
19	Extremely hard	極度辛苦
20	Maximal exertion	極度辛苦,實在無法堅持下去

Instructions to participants

While exercising we want you to rate your perception of exertion, i.e. how heavy and strenuous the exercise feels to you, ***specifically during the last 2 minutes of your walk.***

The perception of exertion depends mainly on the strain and fatigue in your muscles and on your feeling of breathlessness or aches in the chest.

Look at this rating scale. We want you to use this scale from 6 to 20, where 6 means “no exertion at all” and 20 means “maximal exertion”.

9 corresponds to “very light” exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes.

13 on the scale is “somewhat hard” exercise, but it still feels OK to continue.

17 “very hard” is very strenuous. A healthy person can still go on, but he or she really has to push him or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is.

Don’t underestimate it, but don’t overestimate it either. It’s your own feeling of effort and exertion that’s important, not how it compares to other people’s. What other people think is not important either.

Look at the scale and expressions and give a number.

F. Chester Treadmill Test

Table F.1 shows HR and RPE at the four levels of the Chester Treadmill Test completed by Participant 6 at Baseline, recorded against the corresponding $\dot{V}O_2$ values according to **Eq. 4.3**. Participant 6 was 44yrs, hence HR_{max} was estimated at 176bpm and $80\%HR_{max}$ at 141bpm.

Table F.1: Heart rate (bpm) and RPE recorded during the Chester Treadmill Test at Baseline for Participant 6 (44yrs).

level	speed (km/h)	gradient (%)	$\dot{V}O_2$ (ml/kg/min)	heart rate (bpm)	RPE
1	6.2	0	13.83	99	11
2	6.2	3	19.41	115	12
3	6.2	6	24.99	136	13
4	6.2	9	30.57	150	15
5	6.2	12	36.15		
6	6.2	15	41.73		

The test ended at Level 4 because the participant reached $80\%HR_{max}$ and at the same time reported an RPE of 15. The data highlighted in blue was then plotted (**Figure F.1**), and the equation of the line of best fit determined using regression analysis.

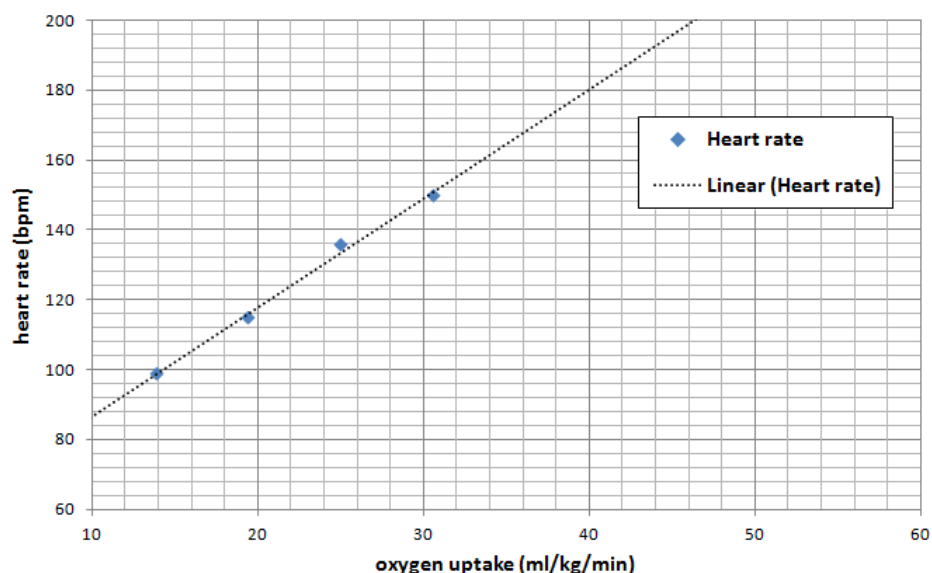


Figure F.1: Heart rate (bpm) vs oxygen uptake (ml/kg/min) for Participant 6 at Baseline.

Linear regression analysis showed

$$HR = 3.1183 \times \dot{V}O_2 + 55.7638, \text{ with } R^2 = 0.995 \text{ (} p=0.003 \text{)}.$$

Impact of hand-held weights on treadmill walking in previously sedentary women

From this equation it followed that HR_{max} would correspond to $\dot{V}O_{2max}$ of 38.56ml/kg/min.

Using this result, the submaximal workload of 60-75% of predicted $\dot{V}O_{2max}$ equates to the range 23.14-28.92ml/kg/min, indicating a target RPE for Participant 6 of between 13 and 15.

G. Energy expenditure when walking

The data presented in **Table G.1** is reproduced from Appendix B of Williams (2010). It was used in the development of the study website (www.sleepy8.com) to estimate total energy expenditure based on a participant's average speed per walk and their body mass.

Table G.1: Approximate energy expenditure (kcal/min) by body mass when walking at different speeds.
(Adapted from Williams, 2010)

average speed of Walk X	Body mass																		
	45kg	48kg	50kg	52kg	55kg	57kg	59kg	61kg	64kg	66kg	68kg	70kg	73kg	75kg	77kg	80kg	82kg	84kg	86kg
4.8km/h	2.7	2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.8	3.9	4.1	4.2	4.4	4.5	4.6	4.8	4.9	5.0	5.2
5.1km/h	3.1	3.3	3.4	3.6	3.8	4.0	4.1	4.3	4.4	4.5	4.7	4.8	5.0	5.2	5.3	5.5	5.6	5.8	5.9
5.6km/h	3.3	3.5	3.7	3.9	4.0	4.2	4.4	4.6	4.7	4.9	5.1	5.3	5.4	5.6	5.8	6.0	6.2	6.3	6.5
6.4km/h	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.7	5.9	6.1	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.9	8.1
7.2km/h	4.7	5.0	5.2	5.4	5.7	5.9	6.2	6.4	6.7	6.9	7.1	7.4	7.6	7.9	8.1	8.3	8.6	8.8	9.1
8.0km/h	5.4	5.7	6.9	6.3	6.5	6.8	7.1	7.4	7.7	7.9	8.2	8.4	8.7	9.0	9.2	9.5	9.8	10.1	10.4
8.7km/h	6.2	6.6	6.9	7.2	7.5	7.9	8.2	8.5	8.8	9.2	9.5	9.8	10.1	10.4	10.8	11.1	11.4	11.8	12.1
9.3km/h	7.7	8.0	8.4	8.8	9.2	9.6	10.0	10.4	10.8	11.1	11.5	11.9	12.3	12.7	13.1	13.5	13.9	14.3	14.7

For example, when walking at an average speed of 6.4km/h, a person weighing 57kg is estimated to expend 5.3kcal/min of energy. Considering the data presented in Table 3.2, this would be an underestimation if hand-held weights of 0.91kg were being used.

H. A priori statistical power calculation

EXECUTIVE SUMMARY

With a sample of 24 subjects per group (HWG and CG) the study will have power of 80%. This means that there is an 80% likelihood that the study will yield a statistically significant effect, and lead to the conclusion that the mean “change in $\dot{V}O_2\text{max}$ ” differs for HWG vs CG.

Details

The study will compare two groups (HWG vs CG) on a scale called “change in $\dot{V}O_2\text{max}$ ”. The null hypothesis is that the mean response for HWG and CG is identical. The intent is to disprove the null, and conclude that the mean change in $\dot{V}O_2\text{max}$ (ml/kg/min) is different for HWG than for CG.

The computation of sample size is based on the following assumptions and decisions.

Group means

The expected mean change in $\dot{V}O_2\text{max}$ for HWG and CG are 7ml/kg/min and 4ml/kg/min, respectively. The common within-group standard deviation is assumed to be 3ml/kg/min.

Justification: The expected distributions are based upon results of two studies.

1. Murphy et al. (2002) observed a mean (\pm SD) increase in $\dot{V}O_2\text{max}$ of $4\pm 3\text{ml/kg/min}$ for 21 participants when they followed a six-week exercise programme of brisk walking in either long (30mins per day for five days each week) or short ($3 \times 10\text{mins}$ for five days each week) bouts. Participants completed 88% and 91% of the required exercise respectively. The study enrolled a total of 32 participants, and nine dropped out (28%). Adequate compliance was defined as the completion of 60% of prescribed walks (equivalent to 3 out of 5 days per week).

2. Duncan et al. (1991) observed a 67% greater increase in $\dot{V}O_{2\max}$ for those participants (all women) who followed a 24-week exercise programme of aerobic walking (up to 8km/h) versus brisk walking (up to 6.4km/h). Participants were required to walk between 2.4km and 4.8km a day on five days each week. Dropout rates in the two groups were 55% and 46% respectively.

Missing

In computing the sample size, it has been assumed that the percentage of missing data will be 30%. This means that for every 100 subjects enrolled in the study, 30 will not provide data and will be excluded from the analysis.

Justification: The level of missing data is comparable with that observed by Murphy et al. (2002) during their 6-week exercise programme.

Sample Size

The study will enrol 24 subjects per group, for a total of 48 subjects. With this sample size, there is an 80% likelihood that the study will yield a statistically significant result, and lead to the conclusion that the mean change in $\dot{V}O_{2\max}$ is different for HWG than for CG.

Understanding the assumptions

The decision to use a sample size of 24 per group is based on the assumptions outlined above. If these assumptions are correct, then this sample size will result in power of 80%. However, if these assumptions are incorrect, then the sample size needed to yield power of 80% will be higher or lower than 24 per group. Therefore, it is instructive to consider what sample size would be required if a different set of assumptions were adopted.

Computation of the required sample size is based on five factors, as follows.

1. Mean difference between groups

One factor that determines the required sample size is the mean difference between groups. A small difference is relatively hard to detect, and therefore requires a larger sample size. Conversely, a large difference is relatively easy to detect, and therefore requires a smaller sample size.

A mean difference of 3ml/kg/min between groups and a required sample size of 24 per group has been specified. If the true mean difference is actually (for example) 10% smaller, a sample size of 30 per group would be needed. By contrast, if the true mean difference is actually 10% larger, a sample size of only 21 per group would be needed.

2. Dispersion of scores

Another factor that determines the required sample size is the dispersion of scores within each group. If scores within each group are clustered in a narrow range, differences between the groups are more obvious and the required sample size is relatively low. By contrast, if the scores within each group fall over a wider range, the difference between groups is less obvious and the required sample size is relatively high.

The dispersion is quantified using the standard deviation of the scores. The standard deviation of 3ml/kg/min used in the computations leads to a required sample size of 24 per group. If the true standard deviation is actually (for example) 10% larger, a sample size of 29 per group would be needed. By contrast, if the true standard deviation is actually 10% smaller, a sample size of only 20 per group would be needed.

3. Missing data

Another factor that determines the required sample size is the percent of missing data. The number of subjects actually needed for the analysis is computed and then that number adjusted to ensure that sufficient data is obtained after the missing subjects are excluded.

In computing the sample size to be 24, a missing data rate of 30% is assumed. If the actual rate of missing data is 28%, a sample size of 24 per group would be needed. Conversely, if the actual rate of missing data is 32%, a sample size of 25 per group would be needed.

Note that the adjustment for missing data assumes that the data are missing completely at random. No attempt is made to adjust for the possibility that subjects who fail to respond differ in some ways from subjects who do provide a response.

4. Alpha

Another factor that has an impact on the required sample size is alpha, the criterion used for statistical significance. An alpha of 0.05 has been used, which is often the default value, in computing the required sample size of 24 per group.

It is sometimes appropriate to select a more conservative criterion. For example, with alpha set at 0.01 the required sample size would be 36 per group. Conversely, it is sometimes appropriate to select a less conservative criterion. For example, with alpha set at 0.10 the required sample size would be 19 per group.

5. Tails

The final factor to consider is whether the significance test is one-tailed or two-tailed. It has been assumed that the study will use a two-tailed test, which is usually appropriate, and computed the required sample size as 24 per group.

If it were appropriate to use a one-tailed test (with alpha at 0.05) the required sample size would be 19 per group.

Concluding remarks

This discussion is intended to highlight the importance of the assumptions in computing sample size.

Disclaimer

This report is intended to help researchers use the program, and not to take the place of consultation with an expert statistician.

This report was generated by *Power and Precision* (BioStat, Englewood, USA) and edited by Deborah Savin.

Justifications: These were added to the report by Deborah Savin.